4.0 GEOLOGY AND HYDROGEOLOGY

The following sections present a summary of the regional and local stratigraphic and structural geology, lithology, hydrostratigraphy and hydrogeology within the Exxon Mobil Corporation (ExxonMobil) geologic study area. Information obtained from the data, interpretations and conclusions of the artificial penetrations review study and from the drilling and completion of other Harris County injection wells were used for the study of the geologic conditions at and surrounding the Pasadena Plant facility. Figure 4-1 is a regional stratigraphic and hydrostratigraphic column showing the relationships of the various formations and aquifers.

4.1. Regional Geology

The ExxonMobil regional geologic study area is located in southeastern Harris County on the Texas Gulf Coast. The regional study area is circular and focuses on Harris County and the counties which surround Harris County.

4.1.1. Regional Stratigraphy

The earliest record of sedimentation in the Gulf of Mexico Basin occurred during the Late Triassic to Early Jurassic when the early phases of continental rifting resulted in the deposition of non-marine red bed and deltaic sediments (shales, siltstones, sandstones and conglomerates) in a series of restricted, graben fault-block basins. These sediments were overlain by a thick sequence of anhydrite and salt beds (Werner Anhydrite and Louann Salt) deposited during Middle Jurassic time. The deposition of the Louann Salt beds was localized within major basins that were defined by the major structural elements in the Gulf Coast Basin. The clastic Norphlet Formation (sandstones and conglomerates) overlies the Louann Salt and is more than 1,000 feet thick in Mississippi but thins westward to a sandstone and siltstone in Texas. Norphlet conglomerates were deposited in coalescing alluvial fans near Appalachian sources and grade down-dip into dune and interdune sandstones deposited on a broad desert plain (Mancini and others, 1985).

Shallow-water carbonate and clastic rocks of the Smackover, Buckner and Haynesville formations and Cotton Valley Group were deposited over the Norphlet Formation from the Late Jurassic into the Late Cretaceous. Jurassic, non-skeletal, carbonate sands and muds accumulated on a ramp-type shelf with reefal buildups developed on subtle topographic highs (Baria and others, 1982). A high terrigenous clastic influx in eastern

Louisiana and Mississippi occurred during deposition of the Haynesville, and diminished westward where the Haynesville Formation grades into the Gilmer Limestone in East Texas. The top of the Jurassic occurs within the Cotton Valley Group, with the Knowles Limestone dated as Early Cretaceous (Berrasian) in age (Todd and Mitchum, 1977). The middle Cretaceous was a period of particular stability, permitting the development of extensive, shelf-edge reef complexes (Baria and others, 1982). Tectonism in the western United States and northern Mexico (Laramide Orogeny) in the Late Cretaceous resulted in a large influx of terrigenous sands and muds (Washita-Fredericksburg and Tuscaloosa Formations) into the Gulf Coast Basin. This effectively shut-off the production of carbonates, except in the Florida and Yucatan regions. The rate of terrigenous sediment influx has been greater than the rate of basin subsidence, resulting in significant progradation of the continental shelf margin since the Cretaceous.

The geometry of Cenozoic deposition in the Gulf Coast Basin was primarily controlled by the interaction of the following factors:

1) Changes in the location and rates of sediment input, resulting in major shifts in the location of areas of maximum sedimentation;
2) Changes in the relative position of sea level, resulting in the development of a series of large-scale depositional cycles throughout Cenozoic time;
3) Diapiric intrusion of salt and shale in response to sediment loading; and
4) Flexures and growth faults due to sediment loading and gravitational instability.

Early Tertiary sediments are thickest in the Rio Grande Embayment of Texas, reflecting the role of the ancestral Rio Grande and Nueces rivers as sediment sources to the Gulf of Mexico. By Oligocene time, deposition had increased to the northeast in the Houston Embayment, suggesting that the ancestral Colorado, Brazos, Sabine and Mississippi rivers were increasing in importance. Figure 4-2 shows these major structural features of the Texas Gulf Coast. Miocene time is marked by an abrupt decrease in the amount of sediment entering the Rio Grande Embayment, with a coincident increase in the rate of sediment supply in southeast Texas, Louisiana and Mississippi. Throughout the Pliocene and Pleistocene Epochs, maximum depocenters of sedimentation were controlled by the Mississippi River and are located offshore of Louisiana and Texas.

Tertiary sediments accumulated to great thicknesses where the continental platform began to build toward the Gulf of Mexico, beyond the underlying Mesozoic shelf margin and onto transitional oceanic crust. Rapid loading of sand on water-saturated prodelta and continental slope muds resulted in contemporaneous growth faulting (Loucks and others, 1986). The effect of this syndepositional faulting was a significant expansion of the sedimentary section on the downthrown side of the faults. Sediment loading also led to salt diapirism, with its associated faulting and formation of large salt withdrawal basins (Galloway and others, 1982a).

Sediments of the Tertiary progradational wedges were deposited in continental, marginal marine, near shore marine, shelf and basinal environments and present a complex depositional system along the Texas Gulf Coast.

Overlying the Tertiary progradational wedges along the Texas Gulf Coast are the Pleistocene and Holocene sediments of the Quaternary Period. Pleistocene sedimentation occurred during a period of complex glacial activity and corresponding sea level changes. As the glaciers made their final retreat, Holocene sediments were being deposited under the influence of an irregular, but rising, sea level. Quaternary sedimentation along the Texas Gulf Coast occurred in fluvial, marginal marine and marine environments. Figure 4-1 displays the depositional and structural framework of the sedimentary column utilized for the injection and confinement of wastes at the ExxonMobil site.

4.1.2. Regional Hydrostratigraphy

Miocene and younger formations contain usable quality water (<3,000 mg/L TDS) and potentially usable quality water (<10,000 mg/L TDS) (base of lowermost USDW). Baker (1979) describes four major hydrogeologic units along the Texas Gulf Coast. These are, from oldest to youngest, the Miocene-aged Jasper Aquifer and the Burkeville confining system, the Miocene-Pliocene-aged Evangeline Aquifer and the Pleistocene-Holocene-aged Chicot Aquifer (Figure 4-3). Fresh water recharge to the aquifer system is primarily from rainfall on the outcrop areas and from rainfall on the surficial aquifer system, which in turn recharges the underlying aquifers.

Most of the ground water in Harris County is supplied by the Evangeline and Chicot aquifers. Large ground water withdrawals for municipal, industrial and agricultural uses from the Evangeline and Chicot aquifers began in the 1930s (Gabrysch, 1980), and in the Houston area, averaged 500 million gallons per day from 1969 through 1982. These large amounts of ground water withdrawal, in excess of natural recharge, have resulted in water-level declines in both the Chicot and Evangeline aquifers throughout Harris

County. Ground water withdrawals from the Chicot and Evangeline aquifers are not expected to have an effect on either the safety of the site (non-endangerment of USDWs) or injection operations, since the water levels are stabilized or rising. Based on the detailed geologic study, no natural conduits (vertically transmissive faults or fractures) exist between the injection sands and the fresh water aquifers. The Frio Formation sands are separated by over 2,000 feet of geologic section from the shallow, fresh water aquifers (<10,000 mg/L TDS). As a result of the above-described conditions in the area of the Pasadena Plant, continued ground water withdrawals from the Chicot or Evangeline aquifers will not have an effect on either non-endangerment or waste containment.

4.1.3. Confining Zone and Injection Zone

The Confining Zone for the ExxonMobil injection wells is the Anahuac Formation. The Injection Zone identified for utilization as a disposal horizon is the Frio Formation. WDW-397 is and WDW-398 will be completed to inject across the middle and basal portions of the Frio Formation.

4.1.3.(a) Confining Zone

The Anahuac Formation has been designated as the Confining Zone for the underlying Frio Formation Injection Zone. (Plate 4-2 [Strike-Oriented Structural Cross Section B-B'] and Plate 4-3 [Dip-Oriented Structural Cross Section A-A']) show the lateral continuity of the Anahuac Formation across the AOR and within the study area. Figure 4-3 is a dip-oriented stratigraphic and hydrogeologic cross section across Harris County which illustrates the positioning of the zones of interest. The Anahuac Formation is predominantly shale, deposited during a major rise in sea level and extends across most of the Gulf Coast Basin. In the local area, a prominent limestone interval (Het lime) is present within the Anahuac Formation. The Het lime interval is easily identifiable on the geophysical well logs as an interval of higher resistivity. The two structural cross sections show the lateral continuity of the Anahuac Formation across the area of review (AOR) and within the study area. Across the study area, the Anahuac Formation thickens southwestward, from about 400 feet in the northwest portion of the study area to over 550 feet in the southeast, forming a thick, continuous wedge across the study area.

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4.1.3.(b) Injection Zone

The Frio Formation is designated as the Injection Zone for this no-migration petition demonstration. Figure 4-4 is a regional structure map of top of the Frio Formation and

Figure 4-5 is a regional total thickness map of the Frio Formation. At the ExxonMobil facility, the top of the Frio Formation is present at a depth of about 5,300 feet relative to ground level. The thickness of the Frio Formation in Harris County ranges from less than 1,000 feet in the northwestern part of the county, to greater than 3,000 feet in thickness in the southeastern part of the county.

4.1.4. Regional Cross Sections

Two regional structural cross sections demonstrate the lateral continuity for the sand and shale (aquiclude) layers within the Frio Formation Injection Zone (Figures 4-6 and 4-7). The cross sections illustrate the continuity and thickness of the Injection Zone across the regional study area.

4.1.5. Regional Structural Geology

Cenozoic sediments were deposited along the margin of the Gulf Coast basin, an extracratonic basin characterized by rapid subsidence in areas of sediment loading. Three major areas characterized by unique structural styles have been defined along the Texas Gulf Coast. These unique structural styles are classified based on the syndepositional province and the type of diapiric sediment involved in deformational processes. They are the Houston Embayment of Southeast Texas, the San Marcos Platform of South Central Texas and the Rio Grande Embayment of South Texas.

ExxonMobil is located in the Houston Embayment, which is characterized by salt diapirism, faulting and unfaulted salt withdrawal sub-basins (Bebout and others, 1978). The Oligocene-Holocene section thickens basinward, periodically interrupted by coast-parallel fault systems and salt diapirism, which often become increasingly complex as they extend upward through the section (Galloway and others, 1982a).

4.1.6. Regional Seismic Activity

The Texas Gulf Coast is historically an area of low seismicity with naturally occurring earthquakes being rare and of low magnitude. ExxonMobil is located in one of the areas recognized as having the lowest level of seismic risk in the continental United States (Figure 4-8). Rare instances of fluid injection-induced and fluid withdrawal-induced earthquakes from oil field operations have been documented along the Texas Gulf Coast. However, fluid injection-induced earthquakes are associated with much higher injection pressures and volumes than encountered in Class I waste injection operations, while fluid withdrawal-induced earthquakes are most commonly associated with large scale oil and gas production of greater magnitude than any past or present production in the Pasadena area.

4.1.7. Regional Ground Water Flow

Ground water in the Coastal Plain aquifers are considered to have two origins: meteoric waters—precipitation that enters the shallow aquifers by infiltration—and formation waters—water trapped in sediments from the original depositional environments (Kreitler, 1979). These two types of waters coexist in the basin in the following three hydrologic regimes: 1) the uppermost permeable strata are continuously re-charged by meteoric waters forming a fresh water regime, which may extend to a depth of several thousand feet below land surface, and where flow is directed down-dip toward the basin center; 2) the underlying compacting strata expel original formation water or water at least several million years old from sediments forming a hydrostatic system, where waters from this essentially saline section can come in contact with the overlying meteoric sections to prevent excessive pressure buildup within the hydrostatic zone; and 3) further down-dip, the underlying strata represent the overpressured or geopressured zone where abnormally high fluid pressures exist due to restricted drainage conditions (Kreitler and Richter, 1986).

In 1987, C. W. Kreitler and M. S. Akhter conducted a geohydrologic characterization study of the Frio Formation to evaluate pressure regimes and their influence on the migration potential of formation fluids. The study utilized pressure data gathered from drillstem tests and bottom-hole pressure measurements in onshore oil and gas wells along the Texas Gulf Coast. The data were used to construct potentiometric surfaces and residual potential surfaces and to assess the effects of depressurization caused by hydrocarbon production. The data indicates that the potential for ground water movement in the Frio Formation is from areas of recharge toward the Gulf (generally northwest to southeast), except in areas where significant hydrocarbon production has occurred.

4.2. *Local Geology*

This discussion addresses the local stratigraphic and structural geology, lithology, hydrostratigraphy and hydrology pertinent to the propose ExxonMobil injection operations. For the purposes of this demonstration, the local geologic area of study is defined as the area within the cone of endangering influence and within the boundaries of the 10,000-year waste plume. Plates 4-1A, 4-1B and 4-1C show the local study area, wells used for geologic interpretation and the locations of local cross section lines constructed for this no-migration petition demonstration. The plates also depict the predicted location of the 10,000-year waste plumes for the Frio D Sand, the Frio E&F Sand and the Frio A/B Sand. A list of well log data used for detailed mapping of the local area is presented on Table 4-1.

4.2.1. *Stratigraphy*

The Injection Interval for the ExxonMobil injection wells is contained within the Frio Formation. Therefore, this local stratigraphy discussion begins with the Frio Formation and then discusses the successive shallower geologic formations.

Frio Formation

Deposition of the progradational Frio wedge was initiated by a major global fall in sea level, with subsequent Frio sediments being deposited under the influence of a slowly rising sea (Galloway and others, 1982b). Figure 4-4 shows a regional structure map on the top of the Frio Formation and Figures 4-6 and 4-7 show regional structural cross sections of the Frio Formation depositional wedge through Harris County. On a regional scale, the Frio and Catahoula formations can be divided into a number of distinct depositional systems that are related spatially and in time. Two major progradational delta complexes designated the Houston and Norias delta systems, identified by Galloway and others (1982b), were centered in the Houston and Rio Grande Embayments, respectively (Figure 4-9). Separating the two delta complexes was a broad barrier island/strand plain system (Greta/Carancahua) along the south central Texas coast. A similar but smaller barrier island/strand plain system (Buna) was deposited by longshore currents off the eastern flank of the Houston delta system (Galloway and others, 1982b). Two Catahoula Formation fluvial systems, the Chita/Corrigan and the Gueydan, respectively, supplied sediment to the delta complexes. Frio sandstones of the Upper Texas Gulf Coast contain a higher percent of quartz, less feldspar, and less volcanic rock fragments (quartzose feldspathic volcanic litharenite), than Frio sandstones (feldspathic litharenite) of the Lower Texas Gulf Coast (Bebout and others, 1978).

4.2.3. USDW, Confining and Injection Zone Description

The approximate depths to the various zones of interest for this no-migration petition demonstration include the following:

Horizon	Depth (BGL)
Base of USDW	3,200'
Top of Confining Zone	4,825'
Top of Injection Zone	5,325'
Top of Injection Interval	5,900'
Base of Injection Interval & Zone	7,250'

BGL – below ground level

4.2.3.(a) Lowest Underground Source of Drinking Water

The base of water having less than 10,000 mg/L total dissolved solids [TDS] is usually picked on electric logs as the depth where the deep resistivity log curve in permeable sand first kicks below 3 ohms. Hydrologists contacted at both the TCEQ in Austin, Texas and United States Geological Survey (USGS) in Houston, Texas use a range of 3 to 6 ohms as read from the deep curve on the electric log for the 10,000 mg/L TDS point, and 10 ohms for the 3,000 mg/L TDS level. Electric log resistivity methods were employed by Baker (1979), Ryder (1988) and Turcan (1966) to determine similar correlations of TDS levels in aquifer systems in the Gulf Coast region. A copy of the Turcan (1966) reference paper is included in Appendix D. Several other papers concerning the estimation of water quality from electrical logs are also included in Appendix D. From Turcan (1966), a reading of 5 ohms of resistivity read from the long-normal curve in clean sand indicates the presence of ground water containing 10,000 mg/L of dissolved solids.

In the general area of WDW-397 and WDW-398, sands containing usable quality water (< 1,000 mg/L TDS) occur to a depth of 1,800 feet and those sands containing potentially usable water (< 3,000 mg/L TDS) occur to a depth of about 2,600 feet. These depths have been established through a survey of selected fresh water wells in the area and by research and review of available published literature. The base of the lowest underground source of drinking water (USDW), defined as ground water containing less than, or equal to, 10,000 mg/L TDS, occurs at a depth of approximately 3,188 feet subsea in the WDW-397 injection well, and at a depth of approximately 3,173 feet subsea in the WDW-398 injection well. Figure 4-13 is a structure contour ~~map of~~ the base of the lowermost USDW in the AOR surrounding the ExxonMobil facility. A list of area wells used for contouring Figure 4-13 is included in Appendix C. Example log analyses and base of USDW selection illustrations (WDW-397, Map Id #30, Map Id #13, Map Id #14, Map Id #19 and Map Id #32) are also included in Appendix C. The base of the lowermost USDW was determined by detailed log analysis of the well logs in the area surrounding the ExxonMobil facility location.

The base of the USDW was conservatively chosen as the depth where the recorded long-normal resistivity in a porous sand was less than, or equal to, 4 ohms. Clean sands which have a long-normal resistivity of greater than 4 ohms are assumed to contain formation water having less than 10,000 mg/L TDS, while those having a long-normal resistivity of less than 4 ohms are assumed to contain formation water having greater than 10,000 mg/L TDS. The base of the USDW was chosen at the base of the deepest sand containing water with a salinity less than or equal to 10,000 mg/L TDS (long-normal resistivity greater than, or equal to 4 ohms).

4.2.3.(b) Confining Zone

The Anahuac Formation serves as the Confining Zone for the underlying Frio Formation Injection Zone. The Anahuac Formation is predominantly shale, deposited during a major rise in sea level and extends across most of the Gulf Coast Basin. The two structural cross sections (Plates 4-2 and 4-3) show the lateral continuity of the Anahuac Formation across the AOR and within the study area. A structure map of the Anahuac Formation (Confining Zone) is included as Plate 4-4. The structure map is mapped on a "marker" within the Anahuac Formation which occurs at a depth of about 5,023 feet subsea in WDW-397 and 5,063 feet subsea in WDW-398. The top of the Confining Zone is present at a depth of about 4,818 feet subsea in WDW-397 and 4,856 feet subsea in WDW-398. The top of the Confining Zone strikes generally southwest to northeast and dips toward the coast. A gross thickness isopach map of the Confining Zone is included as Plate 4-5. The Anahuac Formation in the study area thickens southeastward, from about 200 feet in the northwest portion of the AOR to over 800 feet in the southeast, forming a thick, continuous wedge across the AOR.

Several conventional cores were taken from the micritic limestone section (Het Lime) within the Anahuac Formation during the drilling of Lyondell Chemicals injection well WDW-148. The core data report for WDW-148 is included in Appendix C. WDW-148 is located about 13 miles northeast, and along strike, of the ExxonMobil facility. The cores contained fossiliferous, chalky, cryptocrystalline limestone with dirty shale striations. Core porosities for the limestone ranged from 5 to 12.3 percent and permeabilities ranged from less than 0.1 milliDarcies (mD) (lower limit of the analytical method employed) to 3 mD. This tight limestone interval will add an additional layer of confinement to the Anahuac Formation Confining Zone.

A conventional core, characteristic of the Anahuac Formation shale, obtained during drilling of the Elf Atochem North America, Inc. injection well WDW-230, indicates a bulk porosity of 21.8 percent and a permeability of <0.001 mD from a vertical shale sample using simulated formation brine as the permeate. The WDW-230 injection well is located about 25 miles northwest, and along strike, of the ExxonMobil facility location. The core data report for WDW-230 is included in Appendix C. Petrophysical and mineralogical analysis of several samples from this core showed the composition of the Anahuac Formation to be approximately 48 percent total clay (predominantly illite and smectite, with minor amounts of kaolinite) and 40 percent quartz, with minor amounts of calcite and feldspar. These values are in the range expected for typical Tertiary sedimentary shale.

A conventional core from the Anahuac Formation shale was obtained during drilling of the ExxonMobil WDW-397 injection well. The core data report for WDW-397 is included in Appendix C. Permeability to Frio Formation brine was determined for three samples and ranged from 2.3×10^{-3} mD to 6.2×10^{-4} mD, confirming the tight nature and confining capabilities of the Anahuac Formation. Neither conventional core, nor sidewall cores were collected from the Anahuac Formation during the drilling of the ExxonMobil WDW-398 injection well.

4.2.3.(c) Injection Zone

The Injection Zone for ExxonMobil's WDW-397 and WDW-398 includes the entire upper, middle and lower Frio Formation. The Injection Zone depths in WDW-397 occur from approximately 5,347 feet to 7,272 feet KB. The Injection Zone depths in WDW-398 occur from approximately 5,370 feet to 7,295 feet KB. Note that the base of the Injection Zone in each well is below the total depth of the well. The structure map of the Anahuac Formation Marker (Plate 4-4) mimics the top of the Injection Zone and is about 275 feet above the top of the Injection Zone at the facility location. Plates 4-6 and 4-7 are commercial structure maps (Geomap) within the project area. Plate 4-6 is mapped on the top of the Yeagua Formation and Frio Formation (top of Injection Zone) and Plate 4-7 is mapped on top of the Lower Yeagua (Cook Mountain), in the Vicksburg and the

Textularia Warreni Zone (top of Vicksburg), which is equivalent to the top of the Injection Zone. The structure maps suggest that the strike direction is generally east-west, while the dip direction is generally south. The presence of faulting in the AOR has slightly altered the typical strike and dip from the regionally norm (strike – northeast to southwest; dip – toward the coast). The gross thickness map indicates the wedge shaped nature of the Frio Formation. The Injection Zone is thinnest in the northwest portion of the AOR (1,700 feet) and thickens to over 2,000 feet towards the southeast.

The Injection Zone is segregated into two distinct horizons. Various portions of the Lower Frio Formation comprise the Injection Interval for the ExxonMobil injection wells. The sand layers within the Injection Interval have a net thickness of approximately 720 feet at the injection well locations.

Across the AOR, various portions of the upper Frio Formation serve as containment intervals for the Injection Interval. The containment interval is that portion of the Injection Zone which is present between the top of the Injection Interval and the top of the Injection Zone. The containment interval provides additional low permeability strata which prevent upward movement of injected fluids.

The Frio Formation is more porous and permeable than the shales of the overlying Anahuac Formation and the underlying Vicksburg Formation. Based on electrical log response and core data collected from several Class I injection wells (WDW-148, WDW-147, WDW-36, WDW-169, WDW-222, WDW-172), the permeable horizons within the Injection Zone have an average porosity of 30 percent and an average permeability between 500 mD to 1,000 mD. Core data from several of these Class I injection wells, and the core data collected from WDW-397 and WDW-398 are included in Appendix C. Well logs for most of these wells, as well as from other nearby oil and gas exploration wells are included in Appendix B and Appendix C.

4.2.3.(d) Injection Interval

The Lower Frio Formation sand interval present from approximately 5,922 feet to 7,272 feet KB in the WDW-397 injection well has been designated as the Injection Interval for the ExxonMobil injection wells. The equivalent interval in the WDW-398 injection well is present from 5,965 feet to 7,295 feet KB. Note that the base of the Injection Interval in each well is below the total depth of the well. The Lower Frio Formation sand intervals are identified as the Frio D Sand, the Frio E&F Sand (primary completion interval for

ExxonMobil injection wells) and the Frio A/B Sand. Plates 4-2 and 4-3 are structural, stratigraphic cross sections through the ExxonMobil facility location which depict the sands of interest within the Injection Interval.

Frio D Sand

Plate 4-8 is a structure map on top of the D Sand (the top sand package). The Frio D Sand is defined as the interval located at a log depth between 6,635 feet to 6,664 feet KB in the WDW-397 injection well (see Section 4.3 for discussion of WDW-397 log section across the top of the Frio D Sand and determination of upper Frio D Sand contact). The Frio D Sand is located at a log depth between 6,670 feet to 6,715 feet KB in WDW-398. The structure map suggests that the strike direction is generally east-west, while the dip direction is generally south below the facility location. As with the top of the Injection Zone, the presence of faulting and salt dome structures in the local study area alters the typical strike and dip from the regional norm (strike – northeast to southwest; dip – toward the coast).

A net sand isopach map was constructed from the available geophysical well log data (Plate 4-9). The net sand isopach shows a thin, generally dip-oriented geometry near the plant site, with thickening to the southeast and northwest. The D Sand pinches out to the northeast and is absent across a portion of the study area. The sand body geometry of the Frio D Sand is consistent with the overall deltaic depositional patterns exhibited during Frio time in the Houston Embayment. The Frio D Sand has a net thickness of approximately 29 feet in WDW-397 and 18 feet in WDW-398 and ranges in thickness from 0 feet to +70 feet across the AOR.

To the northwest of the AOR, detailed correlation well logs shows that the Frio D sand is present across the crest of Clinton Dome. The correlation of the Frio D Sand to Clinton Dome is also shown in Plate 4-18 (b-b' Structural Southeast-Northwest Cross Section). This Plate was developed by Sandia Technologies (2000) and was included in the petition demonstration for the nearby Merisol WDW-147 and WDW-319 injection wells. Although the D Sand thins appreciably on the Clinton Dome near the center of the structure, the net sand of the Frio D Sand interval is generally thicker than in the area away from structure. The net sand increase is attributed to fault displacement at the time of deposition which created structural lows which allowed for thicker accumulations of the D Sand, while the structural high on the upthrown side of the fault precluded appreciable sediment accumulation.

Frio E&F Sand

Plate 4-10 is a structure map on top of the E&F Sand (the middle sand package). The Frio E&F Sand is defined as the interval located at a log depth between 6,712 feet to 6,930 feet KB in the WDW-397 injection well. The Frio E&F Sand is present from 6,756 feet to 6,940 feet KB in the WDW-398 injection well. The structure map suggests that the strike direction is generally east-west, while the dip direction is generally south below the facility location. As with the top of the Injection Zone, the presence of faulting in the AOR and nearby salt dome structures has slightly altered the typical strike and dip from the regional norm (strike – northeast to southwest; dip – toward the coast).

In order to gain a more detailed understanding of the sand body geometry of the Frio E&F Sand, a net sand isopach map was constructed from the available geophysical well log data (Plate 4-11). The net sand isopach shows a broadly lobate, strike-oriented geometry near the plant site, thickening from northwest to southeast across the AOR. The sand body geometry of the Frio E&F Sand is consistent with the overall deltaic depositional patterns exhibited during Frio time in the Houston Embayment. The Frio E&F Sand has a net thickness of approximately 188 feet in WDW-397 and approximately 184 feet in WDW-398 and ranges in thickness from +80 feet to +280 feet across the AOR. The Frio E&F Sand is generally "blocky" in the AOR, with thin shales being more prevalent towards the east-southeast.

To the northwest of the AOR, detailed correlation well logs shows that the Frio E&F Sand is present across the crest of Clinton Dome. The correlation of the Frio E&F Sand to Clinton Dome is also shown in Plate 4-18 (b-b' Structural Southeast-Northwest Cross Section). This Plate was developed by Sandia Technologies (2000) and was included in the petition demonstration for the nearby Merisol WDW-147 and WDW-319 injection wells. Although it is likely that the dome was a positive feature during Frio time (300 - 400 feet of thinning of the geologic section between the Anahuac and Vicksburg Formation marker structure points), presence of the lower Frio sands across the dome do not appear to be impacted.

Frio A/B Sand

The Frio A/B Sand is defined as the interval located at a log depth of about 6,960 feet to about 7,126 feet KB in the WDW-397 injection well. The Frio A/B Sand is present from 6,991 feet to 7,155 feet KB in the WDW-398 injection well. The net sand isopach shows a broadly lobate, dip- to strike-oriented geometry near the plant site, and thickening from northwest to southeast across the study area (Plate 4-12). The sand body geometry of the Frio A/B Sand is consistent with the overall deltaic depositional patterns exhibited during Frio time in the Houston Embayment. The Frio A/B Sand has a net thickness of approximately 152 feet in WDW-397 and approximately 147 feet in WDW-398 and ranges in thickness from +70 feet to +190 feet across the AOR. Thin shale breaks are present with the sand body and the sand becomes blockier towards the east-southeast.

Detailed correlation well logs show that the Frio A/B sand is present across the crest of Clinton Dome to the northwest of the AOR. The correlation of the Frio A/B Sand to Clinton Dome is shown in Plate 4-18. The interpretation is illustrated on both the Northwest-Southeast Structural Cross Section (Plate 4-3) and the Net Sand Isopach Map Frio A/B Sand (Plate 4-12). Although it is likely that the dome was a positive feature during Frio time (300 - 400 feet of thinning of the geologic section between the Anahuac and Vicksburg Formation marker structure points), presence of the lower Frio sands across the dome do not appear to be impacted.

Frio C Sand

The Frio C Sand is defined as the interval located at a log depth between 7,097 feet and 7,286 feet in Merisol Plant Well 1 (WDW-147). Neither WDW-397, nor WDW-398, are completed to inject into the Frio C Sand. The estimated top of the Frio C Sand in WDW-397 is at a log depth of about 7,195 feet KB. As with the Frio A/B and Frio E&F sands, the net sand isopach of the Frio C sand shows a broadly lobate, strike-oriented geometry near the plant, with a regional thick oriented from north to south across the AOR. The sand thins to the east-southeast, pinching out into Frio shales approximately six miles southeast of the facility location. This pinch-out is oriented southwest-northeast and can be traced towards Clear Lake Field and Friendswood Field, approximately 10 miles southeast from the ExxonMobil facility location.

A detailed correlation of well logs (Plates 4-17, 4-18 and 4-19) shows that the Frio C sand is present across the crest of Clinton Dome to the northwest of the AOR. The sand body geometry of the Frio C sand is consistent with the overall deltaic depositional patterns exhibited during Frio time in the Houston Embayment. The Frio C sand has a gross thickness of approximately 120 feet at the ExxonMobil facility location and ranges in thickness from +50 feet to +155 feet across the study area (a sand thick is developed at the to the northeast of the ExxonMobil facility location). The Frio C Sand occurs as two blocky lobes separated by a prominent shale unit in the middle portion of the sand.

Across Clinton Dome, the Frio C Sand occurs as a blocky sand unit, without the prominent shale unit. However, thin shale breaks occur in the unit spanning the Frio C Sand interval across Clinton Dome. South and southeast of the ExxonMobil facility location, the Frio C Sand retains its two blocky lobes separated by a prominent shale unit in the middle portion of the sand. The lowermost lobe shales out into the Lower Frio/Upper Vicksburg Formation shale in the vicinity of Fault B. The upper lobe of the Frio C Sand continues to thin further to the southeast, shaling out into the Lower Frio/Upper Vicksburg.

Lower Frio Injection Interval Shale Between the Frio E&F and Frio A/B sands

The shales that separate the Lower Frio Injection Interval sands are generally continuous within the 2.0-mile radius AOR and the surrounding area. These shales form effective barriers to vertical fluid movement. The thickness of shale present between the base of the Frio E&F Sand and the top of the Frio A/B Sand is approximately 18 feet, in WDW-397. The shale thins towards the east (to less than 10 feet), but is present in all the wells that penetrate the top of the Frio A/B Sand. The shale thickens to the north and northwest and is in excess of 50 feet thick in several of the Clinton Dome wells. Confinement and isolation between the Frio E&F Sand and the Frio A/B Sand is demonstrated in the vicinity of the Merisol injection wells, since no injectate was observed in the Frio A/B Sand during drilling of Merisol Plant Well 2 (WDW-319). The High Definition Induction Log from Merisol Plant Well 2 (WDW-319) suggests that injectate from Merisol Plant Well 1 (WDW-147) is confined to the Frio E&F Sand. Since the injectate, on average, is more dense than the native formation brine, the tendency would be for the injectate to move downward from the Frio E&F Sand into the Frio A/B Sand, if the units were in communication. A copy of the WDW-319 well log is included in Appendix B.

4.2.3.(e) Confining Strata Beneath Injection Zone

The confining strata beneath the Injection Zone, is comprised of shales and silts of the Vicksburg-Jackson Groups. Consistent with the porosity and permeability of the overlying Confining Zone shales, it is anticipated that the porosity and permeability of the Vicksburg-Jackson Groups are sufficient to contain any injected fluids which may migrate below the Injection Zone.

4.2.4 Local Structural Cross Sections

Plate 4-2 (Strike-Oriented Structural Cross Section B-B') and Plate 4-3 (Dip-Oriented Structural Cross Section A-A') illustrate the continuity of the Confining Zone, Injection

Zone and Injection Interval within the AOR. Plate 4-3 is a dip-oriented cross-section which passes through the WDW-397 well location. Plate 10-1 (Strike-Oriented Structural Cross Section B-B') and Plate 10-2 (Dip-Oriented Structural Cross Section A-A') are additional structural cross-sections which are included in Appendix J. Plate 10-1 and 4-2 are identical. Plate 10-2 is a dip-oriented structural cross-section which passes through the WDW-398 well location.

The structural cross sections demonstrate the lateral continuity for the sand and shale layers within the Frio Formation Injection Zone and Injection Interval. The sand body geometry of the Frio sands near the Pasadena Plant site is consistent with the overall wave-modified, lobate depositional patterns exhibited during Frio time in this portion of the Houston Embayment.

4.2.5 Structural Geology

The subsurface structure at ExxonMobil is characteristic of the salt deformed sediments of the Houston Embayment of the Texas Gulf Coast. The structural setting of the Confining Zone, Injection Zone and Injection Interval is illustrated on the local structure maps (Plates 4-4, 4-8 and 4-10). Two major structural features (salt domes) in the area control the structural orientation within the AOR. The Clinton Oil Field located about six miles to the northwest of the project location, is centered on the top of the Clinton Dome. A second salt deformation structure, the South Houston Dome, is located about six miles to the southwest of the project location. The South Houston Field is centered on this domal structure. These structural features greatly influence the nature and structural orientation of the formations present below the project locations.

Surface Faults and Lineations

No surface faults have been mapped in the AOR. However, Fisher and others (1972) mapped several lineations through the AOR which can sometimes be indicative of the presence of surface faults. Figure 4-14 is a surface lineament map across the study area. The figure depicts several surface lineations which extend through the AOR. Given the distance traversed by the lineations depicted in Figure 4-14 and the lack of curvature (straight lines), these lines are thought to depict pipelines or utility lines. Surface fault expressions in the area do not typically extend greater than a few miles and are almost never straight. A good illustration is the lineation mapped on Figure 4-14 just south of the AOR. The depicted lineation is about 5 miles in length and "snakes" from south to north. The lineation has been mapped as a surface fault by other researchers and is associated with structural disruption across the top of the South Houston Dome. Figure 4-15 is a geologic atlas map of the project area. The subject surface fault is mapped on this figure in the same location.

Continuity between known surface and subsurface faults has been demonstrated by several investigators. Van Siclen (1967) correlated the Addicks Scarp with the subsurface fault controlling the oil accumulation in the Fairbanks Oil Field, northwest of Houston. Sheets (1974) identified the surface expression of the large Clinton Field fault in northeast Houston. Woodward, Lundgren and Associates (1974) mapped the Ethyl Fault in Pasadena, Texas using dense well control from the surface to a depth of at least 1,000 feet. Because of limited available data and the difficulty in correlating shallow, undifferentiated sediments of electric logs, no additional studies relating surface and subsurface faults were found.

Contradicting the conclusions mentioned above, Verbeek (1979) stated that correlations between surface and subsurface faults are not conclusive because of the large distances (6,000 to 12,000 feet) involved in making the inferred connections. It should also be noted that even if such correlations are valid, deep-seated growth faults are no longer very active and fault displacements in the uppermost few thousand feet are very minor. The Ethyl Fault discussed above illustrates this point (Woodward, Lundgren and Associates, 1974). Displacement does not exceed 36 feet in the uppermost 1,000 feet of beds along the Ethyl Fault.

Investigations show that the rate of movement on surface faults is very low. Verbeek and Clanton (1978) report that contemporary rates of movement on many faults in the Houston area are in the range of 0.2 to 0.79 in/yr. Reid (1973) suggested that the movement on some faults was episodic rather than continuous.

Land subsidence due to large ground water withdrawal has been a subject of serious concern in the Houston-Galveston area. In particular, it is alleged that ground water pumpage and subsequent compaction of the clays in the shallow section has caused existing surface faults to move and new faults to form. However, since the creation of the Harris-Galveston Coastal Subsidence District, ground water withdrawal in the Pasadena area has been significantly reduced which has effectively halted subsidence in the area.

Subsurface Faults

Subsurface structural mapping based on electric log correlations indicates that the strike of Lower Miocene and younger sediments in the area of study is east-northeast to west-southwest. This is parallel to the current coastline and is similar to the trend of other Tertiary sediments along the Texas Gulf Coast. Three structure maps were constructed to illustrate the subsurface structure in the vicinity of the ExxonMobil facility location (key geology well logs are contained in Appendix B). Additionally, two regional structure maps obtained from Geomap are included as Plates 4-6 and 4-7. A structure map on the Anahuac Formation shows that the plant site sits on the western flank of the Lynchburg Field structure, near the south-southwest plunging saddle separating the Clinton Dome (located approximately five miles to the northwest) from the Renee-Lynchburg Field structure (located approximately three miles to the east) (Plate 4-4). The structure maps on top of the Frio D and Frio E&F sands show similar structuring (Plate 4-8 and Plate 4-10). With minor fluctuations and interruptions, depositional dip to the south-southeast in the study area is on the order of 100 feet/mile at the top of the Injection Zone. The rate of dip away from the plant site of the south-southwest plunging saddle is approximately 130 feet/mile at the Vicksburg Formation marker level. The Renee-Lynchburg Field structure is transected by two main southwest-to-northeast trending down-to-the-basin normal faults (labeled Fault A and Fault B). Based on fault cuts in the field wells and contouring, the three main faults that cross-cut Lynchburg Field have throws of 100 to 200 feet at the Frio E&F Sand level. These faults apparently cut through the Frio Formation Injection Zone and the Anahuac Formation Confining Zone (see Plates 4-4, 4-8 and 4-10). The depth to which these faults extend is not known. The subject faults appear to attenuate or totally die out in the Anahuac Formation. These main faults are detailed below:

<u>Fault A</u> – This fault is primarily defined by log cuts on its eastern segment. The westernmost fault cut is found in the Mitchell Energy, Houston Port Authority #1 well located 10,150 feet northeast of the ExxonMobil Injection Well (WDW-397). A 150-foot displacement fault is observed at -5,850 feet subsea. Further, fault cuts are observed to the east of the Mitchell Energy well: in the Amerada Hess, Destec, "A" #2 well, the series of Inexco and Kelly Brock, Kelly Brock Fee wells, the Gulf Coast, Houston Ship Channel #1, and the Gulf Corp., Wilburn #1 well. Measured, displacements range from 100 to 180 feet along the trace of this fault. Fault A separates the high-side structural closure at Renee Field (northeast corner of the Richard & Robert Vince A-76 survey) from the down-thrown four-way closure to the south-southeast.

<u>Fault B</u> – This fault is defined by log cuts on its southern and eastern segments. The southernmost fault cut is found in the Traders, Houston Deepwater Land Co. #1 well located approximately 7,500 feet south of the WDW-397 injection well, with an 80-foot displacement fault observed at -6,660 feet subsea. Additional fault cuts are observed to the northeast of the Traders well in the Frazier, T Jones #1 well, the Ethyl, Ethyl Fee #1 well, and the Frazier Brooks #2 well. On its eastern segment, a fault cut with 90 feet of displacement is observed at a subsea depth of -7,830 feet in the Inexco, Kelly-Brock #1 well. Measured displacements along the trace of Fault B range from 100 to 180 feet along the trace of this fault. Fault B separates the downthrown four-way Renee Field, closure from the downthrown four-way Lynchburg Field closure to the south-southeast.

Additionally, a small displacement splinter fault (Fault A') occurs trending to the northeast of Fault A. This fault is defined by cuts in the Mitchell Energy, Houston Port Authority #1 well (50-foot displacement fault is observed at -6,820 feet subsea) and the L. Bowling, Bynum et al. #1 well (Vicksburg Formation marker faulted-out by a 60-foot fault), located in the Peter J. Duncan A-232 Survey. The splinter fault is not believed to carry much further northeast of the L. Bowling, Bynum et al. #1, as no faults are found in either the Humble Fun # 1 well and the Frazier, Kalb et al. # 1 well, or the wells located near the Lyondell Chemical Company, Plant Well No. 1 (WDW-148) and Plant Well No. 2 (WDW-162) injection wells.

Radial faulting patterns characterize the structuring at the three nearby salt domes: 1) Clinton (located 5.5 miles to the northwest), 2) South Houston (located 6.2 miles to the southwest) and 3) Clear Lake (located 9.0 miles to the southeast). The mapped faults shown on Plates 4-4, 4-8 and 4-10 are supported by missing sections in geophysical well logs (fault cuts) and Texas Railroad Commission field maps.

The Anahuac Formation marker, Top of Frio D Sand and Top of Frio E&F Sand structures at Clinton Dome, located approximately 5.5 miles to the northwest of the plant, were prepared based on fault cuts in the field wells, supported by missing geologic sections, and Texas Railroad Commission field maps for the Miocene 3,800' Sand (Plates 4-13 and 4-14). The main fault transecting Clinton Field is northwest-southeast oriented, down-to-the-northeast, normal fault that sets up the production in the Miocene 3,800' Sand as a high-side fault closure. Orientation of the fault was determined by tracing the trend of the fault-cut arcs in the well logs obtained for this study and the Texas Railroad Commission field maps for the Miocene 3,800' Sand (Plates 4-13 and 4-14). The fault has 300 to 350 feet of throw through the main portion of the field. The main fault is approximately paralleled by a down-to-the-southwest, antithetic fault of smaller throw, resulting in a central graben area that is open towards the southeast. Structural dip on the southeast flank of this central graben area is more similar to the dip found to the north-northeast of the dome, than the steeper dip found on the southern and southwestern flank of the dome. This is expected, since the central graben area compensates between the structure exhibited on the southern and southwestern flank, which is the high point of the field, and the lower angle dip exhibited on the north-northeast flank of the dome. The dip rate of the bedding in the central graben area and southeastern flank of the Clinton Dome structure was determined at the Anahuac Marker level by the difference in depth between several of the field wells in the graben and control at and near the Merisol well (WDW-147) and the Frazier Brooks #1 well. Additionally, structural depths from wells in the adjacent fault blocks on the dome and the known displacement exhibited across the faulting was also used as point of control for the Anahuac Formation marker, Top of Frio D Sand and Top of Frio E&F Sand structure maps.

Clinton Dome

The Clinton Dome is a major structural feature of interest to this demonstration in that its presence is greatly responsible for the projected orientation of the injected waste plume. Clinton Dome is located approximately 5.5 miles to the northwest of the ExxonMobil facility location. Geologic mapping of the dome has been performed in great detail by previous authors (Sandia Technologies LLC(Sandia), 2000) and shows that the structure is complexly faulted, with radial faults emanating away from the crest of the dome. This structuring is typical of piercement-type salt dome structures. Several of the cross sections and structure and isopach maps generated during Sandia's study have been reproduced and are included to illustrate the structure and stratigraphy across the Clinton Dome. Three structural-stratigraphic cross sections were constructed by Sandia Technologies, LLC (2000), for inclusion in the no-migration petition demonstration for the nearby Merisol injection wells (WDW-147 and WDW-319). The cross sections are approximately perpendicular to each other and were constructed to show the broad lateral continuity of the sand injection intervals and shale (aquiclude) containment layers within the Frio Formation Injection Zone. The cross sections illustrate the nature of the subject Injection Interval sands across the Clinton Dome. Plate 4-17 (a-a′ Structural Southwest – Northeast Cross Section) is a structural cross section from southwest to northeast across the southeastern part of the Clinton Dome and 4-18 (b-b′ Structural Southeast – Northwest Cross Section) is a structural cross section from southeast to northwest across the top of the Clinton Dome. Plate 4-19 (c-c′ Structural Southwest – Northeast Cross

Section) is a structural cross section from southwest to northeast across the northwestern part of the Clinton Dome. Plates 4-20 and 4-21 are gross sand isopach maps of the Frio E&F Sand and Frio A/B Sand. These maps provide excellent detail across the Clinton Dome and are directly relevant to the ExxonMobil demonstration in that the subject maps address the structure and stratigraphy of the Frio D, Frio E&F and Frio A/B sands. In addition, Plates 4-13 and 4-14 are historical structure maps of the Miocene 3,800-foot sand present in the Clinton Dome.

4.2.6 Fault Transmissivity

The transmissivity of fluids across a fault must be considered with respect to both lateral (horizontal) and vertical components, requiring an assessment of the likelihood of a sealing surface (top seal and/or lateral seal) being present. Faults, in and of themselves, do not seal (Downey, 1984). However, faults can place porous intervals against seals and form non-transmissive barriers (traps). In a sand-shale geologic sequence, faulting will result in the juxtaposition of like and/or unlike lithologies across the fault plane in three manners: a) sand-to-sand, b) sand-to-shale and c) shale-to-shale. Fault planes are normally inconsequential to migrating fluids, and generally are of significance as sealing surfaces only because they may juxtapose rocks of differing capillary properties and fluid pressures (Downey, 1984; Smith, 1966). Each fault case, based on the juxtaposition of lithologies across the fault, must be considered during an assessment for both lateral and vertical transmissivity.

Because the shales beneath the ExxonMobil facility location are ductile at the depths of interest, the juxtaposition of shale beds or sand-to-shale beds across a fault will form a vertical barrier (seal) to fluid flow, due to their very low vertical permeability. This property of viscoelastic deformation behavior will cause any fractures and/or faults to close very rapidly under the action of the in-situ compressive stresses. This well-known ductile (or plastic) behavior of the geologically young Gulf Coast shales is amply demonstrated by the presence of shale diapir structures and the natural closure of uncased boreholes with time (Johnston and Greene, 1979; Gray and others, 1981; Davis, 1986; Clark and others, 1987; Warner and Syed, 1986; Warner, 1988).

Jones and Haimson (1986) have found that, due to the very plastic nature of the Gulf Coast shales, faults will seal across shale-to-shale contacts, allowing no vertical fluid movement vertically along the fault plane. E. I. du Pont de Nemours and Company conducted a borehole closure test at the Orangefield Dome, which demonstrates the plastic nature of the Gulf Coast shales and the rapidity of shale movement to seal off open areas in the subsurface. The test conclusively demonstrated that the young Miocene shales of the Gulf Coast will flow and seal off an open area in the subsurface in a very short time period (test duration was approximately one week) (Clark and others, 1991).

The potential for fault-plane sand smear material to provide a vertical avenue for fluid movement through shale-to-shale juxtaposed lithologies is minimal in the ExxonMobil facility area. This is due, not only to the ability of the shale layers to deform and close off any open areas in the subsurface, but also due to the fact that it can be shown through stratigraphic and structural analysis that many of the containment interval shale beds have not been faulted through sand beds. Therefore, there is no mechanism to get sand grains into the fault plane.

Vertical Fault Transmissivity

The vertical sealing nature of the faults can be demonstrated by looking at the original formation pressure gradients for sands in the lower Miocene and the sands in the lower Frio. Original formation pressure measurements for the injection interval sands beneath the E. I. du Pont La Porte Plant, located approximately nine miles south-southeast of the ExxonMobil facility show pressure gradients in the range of 0.455 psi/ft to 0.460 psi/ft. These gradients are substantially higher than the pressure gradients measured in the lower Frio beneath the ExxonMobil facility location, which are on the order of 0.432 psi/ft (see Section 7.0). If the nearby faults were vertically transmissive, formation pressure gradients in the Miocene and Frio would be expected to be more similar. Additional evidence of the sealing property of shale-to-shale juxtaposed lithologies can be seen in the numerous oil and gas fields that have fault traps in the Gulf Coast, where both the top seal and the lateral seal are provided by shale beds. Specifically, the shallower Miocene and deeper Vicksburg and Yegua oil and gas accumulations near the plant site provide site specific evidence of vertical seal. The hydrocarbon accumulations would not have occurred if the faults are vertically transmissive.

Smith (1980) presents a mechanism whereby shale may be emplaced along the fault plane to provide an effective seal against vertical fluid movement. Shale can be deformed much more readily prior to failure than sandstone can in a sand-shale sequence. Continued deformation will eventually fault the shales; however, a zone of deformed shale may become greatly attenuated and trapped along the plane of the fault, resulting in a vertical seal.

Therefore, the only mechanism for vertical movement up a fault is through "stair-stepping," whereby the fluid potentially moves laterally across juxtaposed sand-to-sand beds. However, beneath the ExxonMobil facility, the preponderance of shale within the containment interval above the Injection Interval sand will quickly restrict this type of movement, due to the presence of juxtaposed shale-to-shale or sand-to-shale beds. Therefore, criteria can be developed to determine which faults in the vicinity of the ExxonMobil facility are vertically transmissive or form top seals based on the juxtaposition of lithologies across the fault.

1) Juxtaposed shales present in the geologic section have a ductile nature and are likely to have squeezed in from both sides of the fault plane, sealing the fault to fluid movement. The juxtaposition of shale across from a sand bed would also seal the fault to fluid movement. This characteristic of Gulf Coast shales to seal open spaces in the subsurface is a well known and documented phenomena.
2) Where the geologic section is predominately sand, upward fluid movement may take place and would be expected to dissipate through "stair-stepping" into the overlying, juxtaposed sand units, similar to the oil migration in the Niger Delta (Weber and Daukoru, 1975). Were the waste to migrate up through the injection interval and cross the fault, the waste would still be in the Injection Zone on the other side of the fault.

The overlying geologic section of predominately shales (present in the section between the top of the Frio Formation and the injection interval), which provides extensive shale-to-shale contacts along the fault plane, will prevent waste migration out of the Injection Zone.

Lateral Fault Transmissivity

The lateral fluid transmissivity potential of the faults discussed above is dependent on whether the throw of the faults results in sands being juxtaposed against sands, as it appears that the Gulf Coast fault planes themselves do not typically act as lateral barriers to flow. Conclusions from faulting case histories indicate that lateral transmissivity is primarily dependent upon the sand-shale ratio of the displaced section and the permeability of the juxtaposed sections (Smith, 1980). In addition, where faults vary in throw along the fault strike, faulting may be transmissive in one area of the fault plane and non-transmissive in another. Therefore, lateral transmissibility across a fault must be addressed, based on the local juxtaposition of lithologies across that fault. Case studies show, only in special, rare cases where thick, under-compacted shales are interspersed between reservoirs, can clay smears be emplaced along a fault plane between off-set sand beds. The case studies of Gulf Coast reservoirs show where parts of the same sandstone body are juxtaposed across a fault (30 - 300 feet of throw), the faults are laterally transmissive (Smith, 1980). Weber and Daukoru (1975) determined from field evidence that in a young, growth-faulted basin similar to the Texas Gulf Coast, laterally non-transmissive faults are only likely when a given sand body on the high side (hanging wall) of the fault is passed by a sedimentary sequence on the downthrown side (foot wall) that contains more than 25 percent shale beds (excluding the thin shale beds in the sandstone body).

Therefore, criteria can be developed from these case studies to determine which faults in the vicinity of the ExxonMobil facility are laterally transmissive or form lateral seals:

1) Where the sand-shale ratio of the faulted geologic section indicates a substantial amount of impermeable shale (25 percent or greater in shale beds) is present, this shale could be expected to be smeared out along the fault plane during the growth of the fault. This clay smear would impede fluid movement laterally to a juxtaposed sand, resulting in a laterally non-transmissive fault.
2) A fault is laterally sealing where the entire injection interval sand is juxtaposed with a low permeability layer, such as clay or shale.
3) A fault is laterally non-sealing where parts of the same sandstone body (excluding shale beds within a sandstone body) are juxtaposed (Smith, 1966 and 1980).

Detailed review of the cross sections (Plates 4-2 and 4-3) were conducted to determine the lateral transmissivity of the Frio sands based upon the juxtaposed geologic section, following the above outlined criteria.

Lateral transmissivity across the faults located to the east of the ExxonMobil facility is an important consideration for the modeling of fluid flow in the Injection Zone. A site-specific determination of the lateral transmissivity of faulting, based on the previously described criteria, is as follows:

Fault A'

The Frio D Sand is very thin, to absent, at the location of Fault A'. Where the Frio D Sand is present, it is very thin (< 15 feet) and the amount of fault throw (20 - 30 feet) as compared to the sand thickness is sufficient to juxtapose the Frio D Sand against containment interval shale. Therefore, Fault A' is not laterally transmissive with respect to the Frio D Sand across the extent of Fault A'.

Frio E&F Sand is laterally transmissive across this fault due to the small amount of fault throw (20 - 30 feet) as compared to the net sand thickness (220+ feet). The Injection Interval sand is juxtaposed against the same stratigraphic sand body across the fault. The sand has been passed by continuous sand on the downthrown side of the fault.

Frio A/B Sand is laterally transmissive across this fault due to the small amount of fault throw (30 - 50 feet) as compared to the net sand thickness (100+ feet). The Injection Interval sand is juxtaposed against the same stratigraphic sand body or against the Frio E&F Sand across the fault. The sand has been passed by continuous sand on the downthrown side of the fault.

Fault A

Plate 4-15 is a strike-oriented structural cross section which crosses Fault A at two locations. Plate 4-15 depicts the stratigraphy and structure within the Injection Interval across an approximate three (3) mile distance beginning at the WDW-397 injection well and ending to the east of the AOR. Plate 4-16 is a dip-oriented structural cross section which crosses Fault A to the south of the WDW-397 well location. Plate 4-16 depicts the stratigraphy and structure within the Injection Interval across an approximate four (4) mile distance beginning at the WDW-397 injection well and ending to the southeast of the AOR.

As illustrated on Plates 4-15 and 4-16, the Frio D Sand is laterally transmissive across Fault A due to the small amount of fault throw (~20 feet) as compared to the net sand thickness (30+ feet). The Injection Interval sand is juxtaposed against the same stratigraphic sand body across the fault. The sand has been passed by continuous sand on the downthrown side of the fault. It should be noted that the Frio D Sand pinches out to the east of the facility location and is not present where the strike-oriented cross section line (Plate 4-15) crosses Fault A approximately two (2) miles to the east of the WDW-397 injection well.

Frio E&F Sand is laterally transmissive across Fault A due to the small amount of fault throw (20 - 30 feet) as compared to the net sand thickness (180+ feet). The Injection Interval sand is juxtaposed against the same stratigraphic sand body across the fault. The sand has been passed by continuous sand on the downthrown side of the fault. The above outlined criteria show that this fault is laterally transmissive.

Frio A/B Sand is laterally transmissive. Along Fault A, the Frio A/B Sand is juxtaposed against the same stratigraphic sand body across the fault. The sand has been passed by fairly continuous sand on the downthrown side of the fault. The above outlined criteria show that this fault is laterally transmissive.

Fault B

Plate 4-16 is a dip-oriented structural cross section which crosses Fault B to the south of the WDW-397 well location. Plate 4-16 depicts the stratigraphy and structure within the Injection Interval across an approximate four (4) mile distance beginning at the WDW-397 injection well and ending to the southeast of the AOR.

Fault B is scissor-like in nature. To the east of the AOR in the area of the Lynchburg Field, fault throw is on the order of 200 feet. At a distance of about two (2) miles east of the WDW-397 injection well, Fault B changes orientation to a more southwest to northeast trend direction, and fault displacement begins to decrease. Due south of the WDW-397 injection well, fault displacement is on the order of 80 feet.

The Frio D Sand is not laterally transmissive across Fault B due to the large amount of fault throw (>80 feet) as compared to the net sand thickness (30+ feet). The Injection Interval sand is juxtaposed against containment interval shale on the downthrown side of the fault. The containment interval shale bounds the Frio D Sand at the location of Fault B. South southeast of the WDW-397 injection wells, on the downthrown side of Fault B, the Frio D Sand is faulted against the Frio E&F Sand.

Frio E&F Sand is laterally transmissive across this fault in that the amount of fault throw (30 - 200 feet) as compared to the sand thickness (180 - 240+ feet). The Frio E&F Sand is juxtaposed against the same stratigraphic sand body and against the Frio D Sand across the fault. The sand has been passed by continuous sand on the downthrown side of the fault.

Frio A/B Sand is also laterally transmissive across Fault B. Along the fault, the Frio A/B Sand is juxtaposed against either the same stratigraphic sand body or the Frio E&F Sand across the fault. The sand has been passed by fairly continuous sand on the downthrown side of the fault. The above outlined criteria show that this fault is laterally transmissive.

The well test data from injectivity/fall-off pressure tests from the WDW-397 injection well and from the nearby Merisol injection wells (WDW-147 and WDW-319)(see Section 7.0) were reviewed to see if boundaries could be identified from the existing data. Unfortunately, due to the short duration of the fall-off period, it was determined that the faults are located outside of the radius of investigation of the tests.

4.2.7. Confining Zone Faults

The purpose of evaluating a confining layer or layers for containment is to provide assurance against vertical migration of the injected fluid or saline water from the Injection Zone into overlying fresh water bearing aquifers. Such vertical movement may result from:

- Intergranular flow through unbreached confining strata,
- Flow through naturally fractured or faulted confining strata,
- Flow through confining strata with diagenetic secondary porosity,
- Flow through artificially fractured strata, and
- Flow through abandoned, unplugged or improperly plugged wells.

The following discussion explains the above potential pathways of fluid movement.

Naturally Fractured or Faulted Strata

Fractures may create a secondary form of porosity. This porosity is often small in magnitude but effective when interconnected. The effect usually results in an increase in permeability resulting in fluid movement through the fractured rock which may be orders of magnitude more rapid than through similar, unfractured rock. Such transmissive fractures may exist deep in the overpressured zone of the Gulf Coast where increased temperatures and pressures have cemented the sediments into rock (Galloway and others, 1982). However, in unlithified sediments it is probable that fracture planes become filled with material of significantly lower permeability. Thus, it is unlikely that fractures in unlithified Gulf Coastal sediments will effectively transmit fluids.

Because the shales at the Pasadena site are plastic and unconsolidated at the depth of interest, it is unlikely that coherent, transmissive fractures or faults would form. When two bodies of unconsolidated shale, or shale and sand, slide past each other along a fault, it is likely that the fault plane will become filled and sealed with plastic shale. Morrow and others (1984) found that the permeability of fault gouges generally ranged between 1 x 10^{-4} and 1 x 10^{-7} mD. Permeabilities of this magnitude are equal to or less than those of most clay shales in confining layers. Jones and Haimson (1986) have noted that due to the very plastic nature of the Gulf Coast Region shales, faults tend to seal themselves, allowing no vertical fluid movement up the fault plane. Evidence of this sealing tendency can be seen in the numerous oil and gas fields with a fault trapping mechanism. The large amount of hydrocarbon accumulation in these fields would not have occurred if faults served as a vertical conduit. Perkins (1961) postulated that hydrocarbon sealing faults in the Gulf Coast may form from soft shale smearing and impregnating the faulted sandstone face during fault movement. Perkins (1961), "In essence, a natural 'mudcake' is formed over the sand fault plane surface and an impervious barrier is created against which migrating hydrocarbons may accumulate." Clark (1989) presents a similar scenario of the vertically sealing nature of Gulf Coast faults and their effects on ground water flow.

Smith (1980) presents another mechanism for emplacing shale along faults to provide an effective vertical seal against fluid migration. Shale can be deformed much more than sandstone before faulting occurs (Handin, 1983). In the normally-pressured stratigraphic sequence of the Gulf Coast, faults might occur in the sandstone beds whereas the shale beds are merely deformed, or sheared, along the potential fault zone. Continued deformation would eventually fault the shales, but a zone of deformed shale might become greatly attenuated and trapped along the fault, separating sandstones juxtaposed by the fault. The important point is that a fault through partially deformed shale or completely faulted shale would not act as an effective conduit for vertical fluid movement. A field example of this fault plane filling as presented by Smith (1980) is the Mount Enterprise fault system of the Tyler Basin, East Texas. Movement along this fault has juxtaposed two separate sandstone units and created a fault zone which is approximately 3 feet wide. Shale units that are positioned between the two sand units have been deformed and squeezed along the fault zone. This contemporaneous deformation emplaced clay from the shale units in the fault zone. The fault zone clay has mineralogy similar to that of the shale unit samples collected in the area. The clay is not fault gouge material but is apparently a part of the shale formation that has become stretched and trapped in the fault zone.

Cementation of cavities and factures along fault zones and cementation of porous fault zone material, such as fault breccias, by secondary mineral deposits from subsurface waters will also produce a zone that has low permeability to fluid migration (Smith, 1980). The result is a fault plane that contains cemented, low-permeability material which should impede the vertical migration of fluid along the fault.

Kreitler (1977) and Kreitler and others (1977), cite evidence which suggests that Gulf Coast faults, at least in the shallow Plio-Pleistocene section, are sealing or at least partially sealing. The evidence is the difference in observed potentiometric levels and different amounts of ground level subsidence across the Ethyl, Long Point and Eureka Heights faults in the Houston area. In all cases, the side of the fault from which ground water pumpage was heavier exhibited lower potentiometric levels and a greater amount of subsidence. This suggests that these faults are acting as low-permeability barriers.

Artificially Fractured Strata

Injection zones can be artificially fractured if the combined hydrostatic and injection pressure exceeds the hydraulic fracture gradient at that depth. Although artificial fracturing is frequently utilized as a method to enhance hydrocarbon recovery, injection pressures for industrial wells are limited by regulations to prevent such fracturing.

Natural Intergranular Flow

The above discussion suggests that the lithological and structural conditions at the ExxonMobil facility are not conducive to flow through fractures or secondary porosity. Natural intergranular flow, although minimal, is apparently the main type of fluid movement through the shale confining layers at the Pasadena facility location. The main parameter of interest is, when dealing with fluid flow through any medium, permeability and effective porosity of the medium.

Shale is usually considered a good confining rock because of its fine grain size and low permeability. Various studies on shale permeability within the Gulf of Mexico were reviewed to provide an estimate of shale permeability. Published permeability data on shale are notably scarce, for reasons including: the low economic importance of shale to oil companies, the difficulty in obtaining shale cores without damaging or distorting them, and the difficulty and length of time required to perform laboratory permeability measurements. A compilation of published and unpublished data (Table 4-2 - Summary of Published Shale Permeability Data), offers representative shale permeabilities at the depth of interest (about 5,500 to 7,200 feet).

4.2.8. Confining Zone Lithologic and Stress Characteristics

The Confining Zone for ExxonMobil's facility location is the Anahuac Formation. The Anahuac Formation consists predominantly of unlithified marine shale. Electric log spontaneous potential curve patterns indicate most of the Anahuac Formation shale was deposited in an open-shelf environment and is typically composed of calcareous, marine shales with localized, lenticular, micritic limestone units.

Given the plastic and ductile nature of the shales which comprise the Anahuac Formation Confining Zone, the Anahuac Formation is of sufficient thickness (450 feet to 550 feet of net shale) and possesses lithologic and stress characteristics capable of preventing initiation and/or propagation of fractures. Fractures may create a secondary form of porosity through which injected fluids or reservoir fluids could migrate. This porosity is often small in magnitude but effective when interconnected. The effect usually results in an increase in permeability resulting in fluid movement through the fractured rock which may be orders of magnitude more rapid than through similar, unfractured rock. Such transmissive fractures may exist deep in the overpressured zone of the Gulf Coast where increased temperatures and pressures have cemented the sediments into rock (Galloway and others, 1982). However, in unlithified sediments of the Anahuac Formation, it is probable that fracture planes become filled with material of significantly lower permeability. Thus, it is unlikely that fractures in unlithified Gulf Coastal sediments will effectively transmit fluids.

Because the Anahuac Formation shales are plastic and unconsolidated at the depth of interest, it is unlikely that coherent, transmissive fractures would form. When two bodies of unconsolidated shale slide past each other along a fault, it is likely that the fault plane will become filled and sealed with plastic shale. Morrow and others (1984) found that the permeability of fault gouges generally ranged between 1×10^{-4} and 1×10^{-7} mD. Permeabilities of this magnitude are equal to or less than those of most clay shales in confining layers. Jones and Haimson (1986) have noted that due to the plastic nature of the Gulf Coast Region shales, fractures tend to seal themselves, allowing no vertical fluid movement up the fracture plane.

Given the ductile nature of the Confining Zone strata and the overburden pressure at the depth of the Anahuac Formation, any fractures which developed in the zone, would "heal" themselves almost immediately. It is common knowledge that borehole closure in unlithified shale layers occurs in deep boreholes during the drilling and exploration for oil and gas reservoirs in the Texas Gulf Coast. The borehole closure phenomenon is related to the plastic, ductile nature of the shale and the overburden (lithostratigraphic) pressure which squeezes the shale and forces it into the borehole where the lithostratigraphic stress is less. It is anticipated that if any fractures developed in the soft, unlithified Anahuac Formation, a similar phenomenon would occur, effectively sealing or healing the fracture, thus preventing the propagation of fractures.

The ExxonMobil Confining Zone has a net shale content of between 450 to 550 feet in the AOR. In consideration of the information presented above, one can safely state that the Confining Zone contains at least one formation of sufficient thickness and with lithologic and stress characteristics capable of preventing initiation and/or propagation of fractures.

Summary of Confining Zone / Containment Layer Fault and Fracture Transmissivity

The purpose of evaluating a confining layer or layers for containment is to provide assurance against vertical migration of the injected fluid or saline water from the Injection Zone into overlying fresh water bearing aquifers. The previous paragraphs discussed the potential pathways for vertical movement of fluids upward through containment interval sands and shales and the ductile, healing nature of containment interval shale. Specific to this demonstration are Faults A and B which located to the southeast of the ExxonMobil injection well. Both faults transect the Injection Interval and containment interval, but appear to die out in the Anahuac Formation Confining Zone. Given the "healing" nature of confining shales, plus the fact that the Confining Zone is not entirely transected by Faults A or B, the Confining Zone has been determined to be laterally continuous and free of transecting, transmissive faults or fractures over an area sufficient to prevent the movement of fluids into a USDW or fresh water aquifer.

4.2.9. Confining Zone – USDW Separation

The base of the lowermost USDW (<10,000 mg/L TDS) was determined to be consistent with the information provided in Section 4.2.3.(a) for the artificial penetrations located within and near the AOR. The USDW occurs at a log depth of 3,220 feet KB (3,188 feet subsea) in WDW-397 and at a log depth of 3,210 feet KB (3,173 feet subsea) in WDW-

398. The top of the Confining Zone occurs at a depth of about 4,850 feet KB (4,818 feet subsea) in WDW-397. The geologic formations above the Confining Zone are composed of alternating sand and shale packages which reflect changes in sea level during deposition, as well as abandonment and re-establishment of various delta lobes within the Houston Embayment during deposition of the formations. Within 500 feet of the top of the Confining Zone, several clean deltaic sands are present which easily total more than 100 feet in cumulative thickness. These sand packages are separated by shale sequences which have individual thicknesses of as much as 100 feet. Both the sand and shale sequences are laterally extensive across the AOR. These alternating sand and shale layers are well below the base of the USDW and provide an added layer of protection for the USDW in the event of fluid movement in an unlocated borehole or transmissive fault.

4.2.10. Seismic History

The ExxonMobil study area is an area of minimal seismicity as shown by observational data obtained from the National Earthquake Information Center (NEIC, 2007) in Boulder Colorado. This data is presented in Figure 4-16 (Seismic Activity Within 80 Kilometers of the ExxonMobil Facility) and in Table 4-3 (Seismic Event Data Within 80 Kilometers of the ExxonMobil Facility). The northern Texas Gulf Coast has been classified as having no potential for earthquake damage (Algermissen, 1969) as seen in Figure 4-8 (Seismic Risk Map of the United States).

It is important to note that no seismic events have been recorded within the ExxonMobil AOR. The search for recorded seismic events within an 80 kilometer (50 mile) radius indicated that only two seismic events have been observed. One of the events was recorded in 1925 at a distance of 41 kilometers (24.6 miles) east-southeast of ExxonMobil in Galveston Bay. No intensity or magnitude was recorded for the event. One of the events was recorded in 1956 at a distance of 61 kilometers (37.8 miles) southeast of ExxonMobil on the Galveston Island coastline. The maximum magnitude recorded for the event was 3.8.

Given the extremely low level of historical seismic activity within the 80 kilometer radius of the ExxonMobil facility, the fact that no seismic activity has occurred nearer than 41 kilometers to the ExxonMobil facility, and literature data which suggests that there is no potential for earthquake damage in the ExxonMobil study area, the risk for detrimental effects due to seismic activity in the ExxonMobil study area are extremely low.

4.2.11. Surface Geology

The surface geology of the local area is shown on Figure 4-15 (Geologic Atlas of Project Location). The surface deposits on which the ExxonMobil facility is located is described as fill and spoil. The Geologic Atlas describes fill as "material dredged for raising land surface above alluvium and barrier-island deposits and for creating land", and spoil is described as "dredged material along waterways" (Geologic Atlas of Texas, Houston Sheet, 1982).

The uppermost formation underlying the Pasadena facility and which outcrops (is exposed at the surface) in the vicinity of ExxonMobil facility consists of Pleistocene age (age description as related to a Geologic time scale depicting the sediments as younger than approximately 2.5 million years and older than recent time) and is mostly of fluvial (river) and interdistributary (out flowing branches of a river) muds separated by sands of fluvial-deltaic (river/delta) origin. Known as the Beaumont Formation, it is a low permeability clay unit through which little or no recharge occurs to the coastal fresh water drinking aquifers.

The Beaumont Formation outcrops in the vicinity of Pasadena and is described in the atlas as "mostly clay, silt, and sand; includes mainly stream channel, point-bar, natural levee, backswamp, and to a lesser extent coastal marsh and mud-flat deposits; concretions of calcium carbonate, iron oxide, and iron-manganese oxides in zone of weathering; surface almost featureless, characterized by relict river channels shown by meander patterns and pimple mounds on meanderbelt ridges, separated by areas of low, relatively smooth, featureless backswamp deposits without pimple mounds; thickness +/-100 feet" (Geologic Atlas of Texas, Houston Sheet, 1982). Other areas of the Beaumont Formation are described as "dominantly clay and mud of low permeability, high water-holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, level to depressed relief, low shear strength, and high plasticity; geologic units include interdistributary muds, abandoned channel-fill muds, and overbank fluvial muds" and "dominantly clayey sand and silt of moderate permeability and drainage, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, and high shear strength; geologic units include meanderbelt, levee, crevasse splay, and distributary sands." There is little or no surface recharge to coastal aquifers in the vicinity of Pasadena because the local area, like the surrounding region, is underlain by the impermeable Beaumont Formation.

In addition to fill and spoil, the atlas depicts other Holocene age (age description as related to a Geologic time scale depicting the sediments as being deposited in recent time) sediments along the coastline in the vicinity of Pasadena. These Holocene age sediments include alluvium (stream deposits). Alluvium is described as "clay, silt, and sand, organic matter abundant locally; includes point-bar, natural levee, stream channel, backswamp, coastal marsh, mud-flat, and narrow beach deposits."

4.3. Well Logs

A set of well logs utilized in the interpretation of the geology in and around the AOR are included in Appendix B of the original set of this no-migration petition demonstration.

WDW-397 Well Log and Top of Frio D Sand

Sand and shale contacts for Gulf Coast sediments are typically chosen based on spontaneous potential (SP) and/or gamma ray (GR) response. However, due to the longstring casing set point for WDW-397 within the Frio D Sand, and logging tool configuration, it is difficult to select an exact depth to the top of the Frio D Sand using the SP or GR response. As such, the top contact of the Frio D Sand was chosen based on the weight of evidence from the logs, drilling penetration rates and lithilogic indications.

The composite log for WDW-397 is a Halliburton High Res Array Ind Density Neutron Longspace Sonic log composed of four (4) logging runs. Run #2 (Halliburton Array Induction Long Spaced Sonic Log ran February 9, 2006) was run before the 9 5/8-inch casing was set and the logged interval is from 6,627 feet KB to 3,363 feet KB. For Run #2, due to logging tool configuration and depth to bottom hole, the first readings are resistivity (starting at 6,630 feet KB), SP at 6,622 feet KB and GR at about 6,572 feet KB. Borehole caliper starts at 6,598 feet KB. Using the sand package present from 6,422 feet KB to 6,444 feet KB as a "type" log sequence representative of a "sand" pick, the resistivity curves suggest the top of the Frio D Sand is below 6,630 feet KB.

Run #3 (Halliburton Long Spaced Sonic Array Induction Log ran February 27, 2006) was run after the 9 5/8-inch casing was set to 6,634 feet KB and the logged interval was reported to be from 7,236 feet KB to 6,634 feet KB. However, GR and SP response were actually logged up to about 6,572 feet. Above the casing set point, the SP is flat (indicating that the tool is in casing), and the caliper response also indicates that the tool is in casing. The GR response from 6,634 feet KB to approximately 6,572 feet KB is suppressed due to the presence of casing, larger borehole and cement. The GR response incorrectly suggests the presence of sand, while the other log signatures correctly indicate the presence of shale. Using the sand package present from 6,766 feet KB to 6,846 feet KB as a "type" log sequence representative of a "sand" pick below the casing point at 6,634 feet KB, the SP, GR, caliper and resistivity curves suggest that the bottom of the Frio D Sand is at a depth of 6,664 feet KB.

The evaluation of Runs #2 and #3 suggests the top of the Frio D Sand is within an approximate 10-foot interval from 6,630 feet KB to 6,640 feet KB which is not logged in adequate detail to allow an exact determination for the top. The resistivity curve on the Halliburton High Res Array Ind Density Neutron LongSpace Sonic Log dated March 8, 2006 illustrates the 10-foot "gap" in log coverage.

To approximate the top of the Frio D Sand, the Mudlogging Company USA, LP Physical Formation Measured Depth Mudlog (recorded in the well at the time of drilling) was examined. The subject log was available in three (3) scales (1" =100'; 2" =100' and 5" =100'). Examination of the these logs across the interval from 6,630 feet KB to 6,640 feet KB suggest that drill penetration rate increased at a depth of about 6,635 feet KB. Percent lithology and drill cutting descriptions both suggest that a more sand rich interval had been penetrated at that depth. A copy of a portion the 1" =100' mud log across the interval of interest is included in Appendix B.

Based on a review of the Halliburton Array Induction Long Spaced Sonic Log ran February 9, 2006, the Halliburton Long Spaced Sonic Array Induction Log ran February 27, 2006 and the Halliburton High Res Array Ind Density Neutron Longspace Sonic Log dated March 8, 2006, the base of the Frio D Sand is present at a depth of 6,664 feet KB and the top of the Frio D Sand is present between a depth of 6,630 feet KB and 6,640 feet KB. A review of the Mudlogging Company USA, LP Physical Formation Measured Depth Mudlog provides information which suggests that the approximate top of the Frio D Sand is at 6,635 feet KB. Therefore, for purposes of this demonstration, the Frio D Sand has been determined to be present in the WDW-397 injection well between a depth of 6,635 feet KB to 6,664 feet KB.

WDW-398 Well Log and Frio D Sand

The composite log for WDW-398 is a Halliburton Array Induction Log composed of three (3) logging runs. Run #1 (Halliburton Array Induction Log ran June 18, 2009) was run before the 13 3/8-inch surface casing was set and the logged interval is from 3,384 feet KB to 90 feet KB. Run #2 (Halliburton Array Induction Dual Spaced Neutron Spectral Density Microlog ran July 1, 2009) was run before the 9 5/8-inch casing was set and the logged interval is from 6,827 feet KB to 3,370 feet KB. Run #3 (Halliburton Array Induction Dual Spaced Neutron Spectral Density Log ran July 18, 2009) was run prior to installation of the screen and gravel pack and the logged interval is from 7,230 feet KB to 6,757 feet KB. The composite log for these three (3) logging runs is included in Appendix B. The three (3) individual logs are included in Appendix J (see "sub" Appendix I which is included in Appendix J).

Based on an evaluation of the composite log (included in Appendix B) and the three (3) individual logs (included in "sub" Appendix I which is included in Appendix J), correlations with WDW-397 and other nearby well logs, the Frio D Sand was determined to be present from 6,670 feet to 6,715 feet KB in WDW-398. The Frio D Sand is poorly developed at the location of WDW-398, and as stated later in the document, was not completed for injection. At the location of WDW-398, the Frio D Sand is predominantly shale, but does contain minor sand layers. Based on evaluation of the Halliburton Array Induction Dual Spaced Neutron Spectral Density Microlog ran July 1, 2009 (included in "sub" Appendix I which is included in Appendix J), four (4) sand "strings" were identified in the interval from 6,670 feet to 6,715 feet KB in WDW-398. The total sand thickness of these sand layers totals 18 feet.

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TABLE 4-1

WELL DATA USED FOR STRUCTURAL MAPPING

Exxon Mobil Corporation
Pasadena, Texas

Map ID No.	Operator	Lease	Well No.	Field	Location	Total Depth
--	A. Plummer et al	J. B. Hines et al	1	Wildcat	A. McCormick, A-46	8,184
DB-185	Acco Oil & Gas Co.	Mamie O. Furr	1	Clinton	C. Martinez, A-545	6,612
24	Amerada Hess Corp.	Destec A	2	Jacinto Port	R. & R. Vince, A-76	10,810
--	American Hunter Expl Ltd	Northern Railway	1	Wildcat	J. Harrell, A-330	12,409
29	American Hunter Expl Ltd	Sam Houston	1	Wildcat	R. & R. Vince, A-76	11,800
--	Ballard Exploration Co.	Channelview Townsite	1	Wildcat	P. Duncan, A-232	10,192
--	Ballard Exploration Co.	Channelview Townsite	2	Wildcat	P. Duncan, A-232	10,990
--	Ballard Exploration Co.	Channelview Townsite	4B	Wildcat	P. Duncan, A-232	10,842
--	Ballard Exploration Co.	West Channelview Townsite	1st	Wildcat	P. Duncan, A-232	10,489
27	Ballard Exploration Co.	Jacintoport	1	Wildcat	R. & R. Vince, A-76	12,335
28	Ballard Exploration Co.	H.S.C. Unit	1st	Wildcat	R. & R. Vince, A-76	12,149
13	Bunte Prod. & J. W. Frazier	Houston Deepwater Land Co.	1	Wildcat	T. Earle, A-18	6,901
--	Circle W Oil	Houston Realty	1	Wildcat	W. T. Carter III, A-1708	6,027
--	Cobra Operating Co.	Northern Railway	1	Wildcat	J. Harrell, A-330	10,913
11	Cockburn Oil Co.	R. E. Brooks Estate	1	Wildcat	R. & R. Vince, A-76	5,745
--	Cyprus Oil	L. M. Ricks	1	Wildcat	S. Singleton, A-704	7,624
WDW-222	DOW Hampshire	Disposal	1	Disposal Well	G. Ross, A-646	7,644
WDW-223	DOW Hampshire	Disposal	2	Wildcat	G. Ross, A-646	7,665
--	Eddy Refg.	W. Brady Unit	1	Clinton	E. Shipman, A-68	9,934
DB-41	Eddy Refining Co.	K. S. Sanders etal	1	Clinton	Reels & Trobough, A-59	8,857
12	Ethyl Corp.	Ehtyl Fee	1	Wildcat	T. Earle, A-18	8,509
WDW-397	ExxonMobil	Agrifos Fertilizer Plant	1	Agrifos Fertilizer Plant	J. Seymore, A-698	7,137
WDW-398	ExxonMobil	Agrifos Fertilizer Plant	2	Agrifos Fertilizer Plant	W. Vince, A-78	7,234
--	Frazier et al	Hornberger Jr et al	1	Wildcat	B. Sessums, A-733	5,526
--	Giddons et al	W. D Sutherland	1	Wildcat	E. Brinson, A-5	8,003
--	Gulf Coast Lse Hold	Ho Ship Channel Nav	1	Wildcat	M. Harris & D. Carpenter, A-28	8,216
--	H. C. Cockburn	T. White	1	Lynchburg	M. Harris & D. Carpenter, A-28	6,017
23A	Halbouty & Moody	So. Texas Nat'l Bank	1	Wildcat	Callahan & Vince, A-9	8,379
--	Hero Corp. of Texas	Gibraller Savings	1	Wildcat	S. Singleton, A-707	9,520
--	Houston O.	Carter Inv. Co.	1	Wildcat	T. Patching, A-619	6,524
--	Humble	Mrs. M. O. Furr	1	Wildcat	S. Singleton, A-706	9,510
--	Inexco Oil Co.	Inexco Fee	1	Wildcat	P. Duncan, A-232	7,015
15	Inexco Oil Co.	H.S.C. Navigation Dist	1	Greens Bayou	R. & R. Vince, A-76	8,143
--	Inexco Oil Co.	Brock, X	1C	Wildcat	R. & R. Vince, A-76	7,915
--	Inexco Oil Co.	Kelly Brock	1	Wildcat	R. & R. Vince, A-76	8,000
--	Inexco Oil Co.	Kelly Brock	1	Wildcat	R. & R. Vince, A-76	8,075
--	Inexco Oil Co.	Jacintoport	1	Wildcat	R. & R. Vince, A-76	8,378
DB-170	Intex Oil Co	Ezell-Mager	1	Clinton	Reels & Trobough, A-59	8,478
--	Irwin et al	Hines et al	1	Wildcat	A. McCormick, A-46	8,585
21	J. C. Stribling & Co.	C. E. Seureau	1	Wildcat	Harris & Wilson, A-31	3,700
DB-22	J. F. Merrick	Weber	1	Clinton	Reels & Trobough, A-59	7,012
--	J. Frazier et al	Westcamp Lake	1	Wildcat	R. White, A-84	5,514
19	Jack W. Frazier	Brooks	1	Greens Bayou	R. & R. Vince, A-76	5,618
14	Jack W. Frazier	R. E. Brooks Estate	2	Wildcat	R. & R. Vince, A-76	8,328
2	Jack W. Frazier	Greens Bayou Homesite	1	Wildcat	S. C. Hirams, A-33	5,301
13	Jack W. Frazier	Houston Deepwater Land Co.	2	Wildcat	T. Earle, A-18	7,743
DB-211	Jack W. Frazier	Houston Deepwater Land Co.	1	Wildcat	T. Earle, A-18	8,602

TABLE 4-1

WELL DATA USED FOR STRUCTURAL MAPPING

Exxon Mobil Corporation
Pasadena, Texas

Map ID No.	Operator	Lease	Well No.	Field	Location	Total Depth
--	Kelly -Brock	Kelly-Brock Fee	2	Wildcat	R. & R. Vince, A-76	7,515
--	L Bowling et al	H. L. Downey©	1	Wildcat	T. Patching, A-619	5,047
22	L U Rowntree	Greens Bayou Homesite	1	Wildcat	S. C. Hirams, A-33	2,500
--	Lanum Pet	Rohm & Haas	1	Wildcat	G. Ross, A-646	6,157
DB-218	Largo Pet Co	25 Hundred Univ	1	Wildcat	W, Jones, A-482	8,313
--	Lemarco Oper.	J. Grizzard	1	Wildcat	T. Patching, A-619	10,200
WDW-148	Lyondell	Disposal	1	Waste Disposal Well	P. Duncan, A-232	7,105
WDW-162	Lyondell	Disposal	2	Waste Disposal Well	P. Duncan, A-232	7,242
DB-219	M P S Prod	C Dwyer et al	1	Wildcat	G. Patrick, A-624	7,025
--	M. S. Hunt	L. H. Curlin	1	Wildcat	G. Ross, A-646	8,556
--	Maguire Oil	Hahn	2	Wildcat	J. Moody, A-546	7,350
1	McCormick etal	Greens Bayou Homesite	1	Greens Bayou	S. C. Hirams, A-33	6,514
30	Merisol USA (WDW-147)	Merichem-Pennwalt	1	Disposal Well	R. & R. Vince, A-76	7,336
31	Merisol USA WDW-319)	Merichem-Pennwalt	2	Disposal Well	R. & R. Vince, A-76	7,408
--	Midwest Oil	Rohm & Haas	1	Wildcat	G. Ross, A-646	8,540
16	Mitchell Energy Corp.	Houston Port Authority	1	Wildcat	R. & R. Vince, A-76	8,200
DB-219	Ohio	S. Myers	1	Wildcat	G. Patrick, A-624	8,500
DB-32	Pan American	J. P. Rembert	1	Clinton	Reels & Trobough, A-59	9,803
--	Production Services	Furr	3	Clinton	Reels & Trobough, A-59	6,534
--	R. E. Best	R. E. Smith Est	1	Wildcat	N. Clopper, A-198	8,313
--	R. H. Hedge	Homecraft Corp.	1	Wildcat	S. Singleton, A-705	7,650
--	Rep. Natural Gas	J. Hornberger et al	1WC	Wildcat	B. Sessums, A-736	10,700
DB-193	Roberts-Whitson O & G Co.	Mamie O. Furr	1	Clinton	C. Martinez, A-545	6,700
20	Rycade Oil Corp.	W. R. Parker	1	Wildcat	Harris & Wilson, A-31	4,050
--	San Jacinto Pet Co.	Hornberger Jr et al	1	Wildcat	B. Sessums, A-734	7,700
DB-3	Scurlock Trust	Clinton	2A	Clinton	Reels & Trobough, A-59	9,145
WDW-173	Shell Oil Co.	Disposal	2	DeerPark	G. Patrick, A-624	7,693
WDW-172	Shell Oil Co.	Disposal	1	DeerPark	J. Woods, A-637	7,657
DB-145	Sun	Oates	1	Clinton	Reels & Trobough, A-59	7,323
--	Tenneco Oil Co.	Tenneco Chemical Inc.	1	Jacinto Port	T. Earle, A-18	8,416
WDW-169	Texas Molecular	Disposal	1	DeerPark	G. Ross, A-646	7,450
WDW-249	Texas Molecular	Wildcat	2	Wildcat	G. Ross, A-646	7,465
DB-212	Tidewater	Hou Deepwater Ltd Co	1	Wildcat	T. Earle, A-18	7,495
32	Traders Oil Co.	Houston Deepwater Land Co.	1	Wildcat	J. Seymore, A-698	7,343
6	Turnbull, et al	R. Brocks Est.	1	Wildcat	R. & R. Vince, A-76	6,015
--	V. B. Russek Jr.	Diamond Shamrock	1	Wildcat	G. Patrick, A-624	7,497
WDW-157	Vopak	Waste Disposal Well	1	Wildcat	G. Ross, A-646	7,525
--	Walter Oil & Gas Corp.	Hornberger Unit	1	Wildcat	B. Sessums, A-735	9,750
--	West Prod	Underwood	1	Wildcat	N. Clopper, A-198	8,338
DB-210	Wilhite Oil Co.	H.S.C. Navigation Dist	1	Wildcat	E. Thomas, A-73	5,152
25	Wm Herbert Hunt Trust	Destec A	1	Wildcat	R. & R. Vince, A-76	10,700

NOTES: NR - not recorded

TABLE 4-2

SUMMARY OF PUBLISHED SHALE PERMEABILITY DATA

Exxon Mobil Corporation
Pasadena, Texas

MATERIAL	DEPTH (feet)	ϕ	k (milliDarcies)	PERMEANT	REFERENCE	REMARKS
Gulf Coast sediments (various locations)	6,562	0.26	1.62×10^{-4}	35% Seawater	Bryant and others, 1975	Lab Consolidation Test performed on loose sediment. Depth of burial simulated by varying confining pressure on sample.
Silty clay – South Pass Mississippi Delta	6,562	0.26	1.00×10^{-5}	Not stated	Bryant and others, 1981	Lab Consolidation Test. Porosity of 26% used from Bryant and others, 1975, which is equivalent to a burial depth of 6,562 feet.
Marine Sediment DSDP Leg 40	6,562	0.26	1.00×10^{-5}	Not stated	Bryant and others, 1981	Lab Consolidation Test. See remarks above.
Shale, Orange Co., Texas	6,041	0.25	3.74×10^{-2} 5.34×10^{-2}	0.2N NaCl solution	URM Technical Report, 1986	Flex wall permeameter used. Cores tested in a dried out expanded state. Thus, reported permeabilities thought to be high.
	6,562	0.25	1.00×10^{-4} 1.00×10^{-5}	None used	Borst, 1983	Theoretical study based on the relationship of permeability to other pore parameters (porosity, pore surface area, mean pore size) and depth of burial and age.
Catahoula shale, Live Oak Co., Texas (Oligocene)	Outcrop	-	3.33×10^{-3}	High density deionized water	Sanks and others, 1975	Reported permeabilities are probably higher than the equivalent shales in subsurface – see text for discussion.
Shale samples 1. Colorado Co., Texas 2. Neves Field Montana 3. Havenweep Field Utah 4. Stockholm Field OK	 9,057 7,067 5,880 4,155	 - - - -	 4.00×10^{-4} 6.00×10^{-4} 7.00×10^{-6} 8.00×10^{-4}	 0.2N NaCl solution 0.02 n NaCl solution 0.2N NaCl solution 0.2N NaCl solution	 Gondouin and Scala, 1958	 Shale permeabilities measured as part of a study on the electrochemical properties of shale.
Eau Claire Shale	1,790 – 2,050	0.01 – 0.15	$<1.00 \times 10^{-3}$	Water	Warner and Syed, 1984	Whole core analysis on the caprock of gas storage reservoir.
Pierre Shale (Cretaceous)	5,250	-	2.99×10^{-6}	Not stated	Bredehoeft and others, 1983	Lab Consolidation Test. Depth given is about equal to the testing confining pressure of 15,900 kPa.
Huron Shale, Ohio River Valley (Upper Devonian) Marcellus Shale, West Virginia (Mid Devonian)	3,325 7,449	<0.001 0.09	7.80×10^{-5} 1.91×10^{-2}	Nitrogen gas Nitrogen gas	Soeder, 1986	Shales are commercial gas reservoirs in the Appalachian Basin.
Wyoming bentonite Natural shale		0.34 0.24	4.16×10^{-6} 1.35×10^{-5}	0.5N NaCl solution 0.121N NaCl solution	McKelvey and Milne, 1962	
Kaolinite		0.23		0.002N NaCl solution	Olsen, 1966	

TERRA DYNAMICS INC

TABLE 4-3

SEISMIC EVENT DATA WITHIN 80 KM OF EXXONMOBIL FACILITY

Exxon Mobil Corporation
Pasadena, Texas

U N I T E D S T A T E S G E O L O G I C A L S U R V E Y

E A R T H Q U A K E D A T A B A S E

FILE CREATED: Mon Mar 11 03:44:12 2009
Circle Search Earthquakes= 2
Circle Center Point Latitude: 29.737N Longitude: 95.198W
Radius: 80.000 km
Catalog Used: SRA
Data Selection: Eastern, Central and Mountain States of U.S. (SRA)

CATALOG SOURCE	DATE YEAR	MO	DA	ORIGIN TIME		***COORDINATES** LAT	LONG	DEPTH km	pP	STD DEV	*****MAGNITUDES**** mb	OBS	Ms	OBS	CONTRIBUTED VALUES	F-E REG	STA	****INFORMATION**** IEMFMDIPF NFAPOEDFL TFPS PEDG	PHENOMENA DTSVNWG	RADIAL DIST km
SRA	1925				Z	29.600	-94.800									503	F	4........	....	41
SRA	1956	01	07	2330	Z	29.300	-94.800								3.80FASRA	503	F	4........	....?..	61

TERRA DYNAMICS INC

PERIOD	EPOCH	STAGE OR GROUP	FORMATION	ENVIRONMENT OF DEPOSITION/LITHOLOGY	
QUATERNARY	HOLOCENE	UNDIFFERENTIATED		Fluvial deposits Medium based sandstones, conglomerates and shales	
		12,000 ybp			
QUATERNARY	PLEISTOCENE	HOUSTON L. WISCONSIN	BEAUMONT	Fluvian and deltaic deposits	
QUATERNARY	PLEISTOCENE	WISONSIN E. WISCONSIN	BEAUMONT		
QUATERNARY	PLEISTOCENE	SANGAMON L. ILLINOIAN	BEAUMONT		
QUATERNARY	PLEISTOCENE	PRE-SANGOMAN E. ILLINOIAN	LISSIE	Medium bedded sandstones and shales	
QUATERNARY	PLEISTOCENE	YARMOUTH KANSAN	LISSIE		
QUATERNARY	PLEISTOCENE	AFTONIAN NEBRASKAN	WILLIS		
		2.8 mybp			
TERTIARY	PLIOCENE	CITRONELLE GROUP	GOLIAD	Fluvial, deltaic and marginal marine deposits Medium to thinnly bedded sandstones and shales	
		5.2 mybp			
TERTIARY	MIOCENE	FLEMING GROUP	LARGARTO	Prodelta, delta front and delta destructional deposits Medium to thinnly bedded sandstones and shales	
TERTIARY	MIOCENE	FLEMING GROUP	OAKVILLE	Channel, meanderbelt and crevasse splay deposits Medium bedded sandstones and shales	
		24 mybp			
TERTIARY	OLIGOCENE	CATAHOULA GROUP	ANAHUAC	Outer shelf and slope deposits Massive shale with basal sandstone and localized limestones (Het. Limestone)	CONFINING ZONE
TERTIARY	OLIGOCENE	CATAHOULA GROUP	FRIO	Aggradational shoreface and beach deposits Massively bedded sandstones and shales	INJECTION ZONE INJECTION INTERVAL
TERTIARY	OLIGOCENE	VICKSBURG GROUP	VICKSBURG	Deltaic, outer shelf and slope deposits Massively bedded shales and medium bedded sandstones	
		37 mybp			

FIGURE 4-1

STRATIGRAPHIC COLUMN OF THE TEXAS GULF COAST

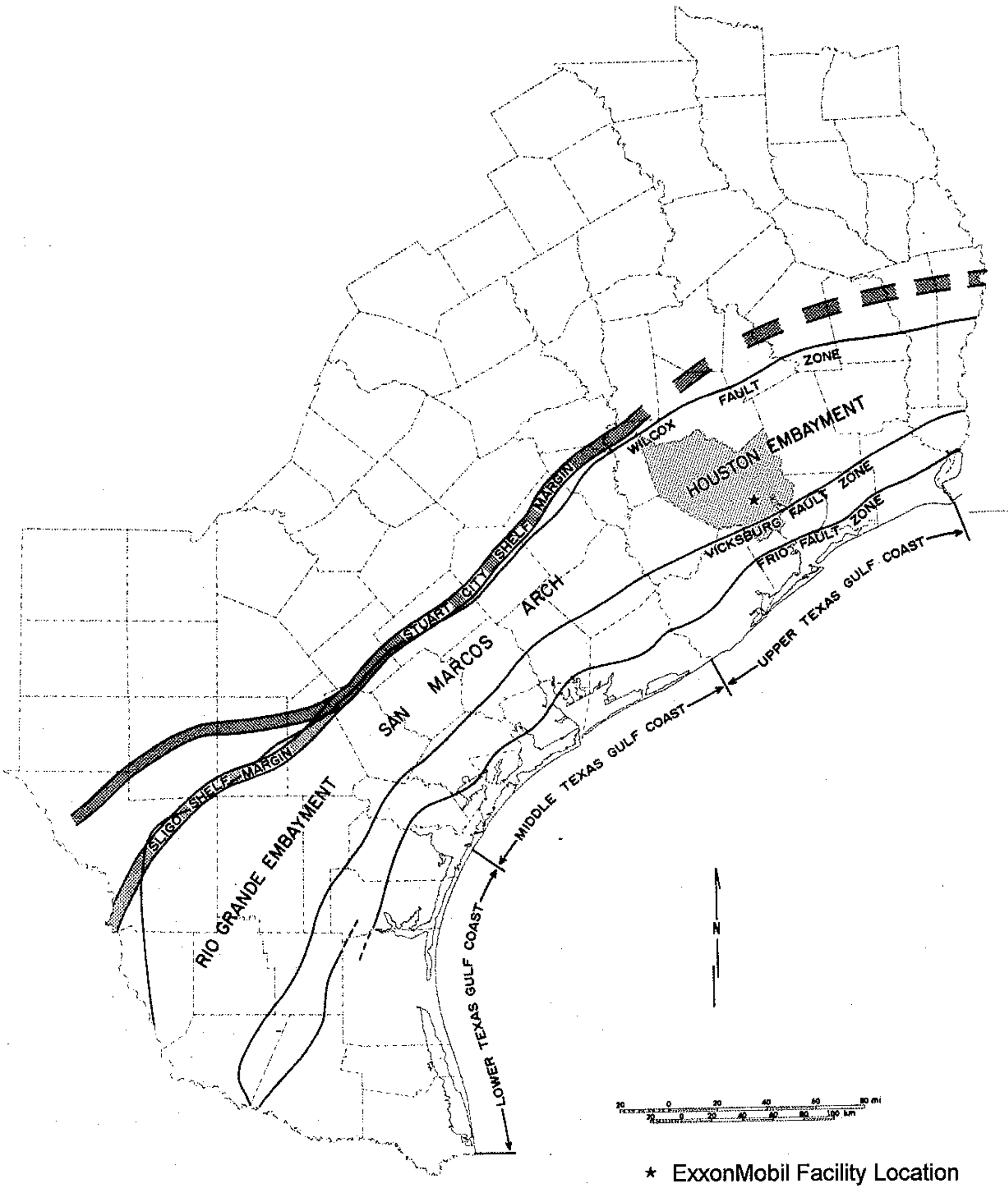
PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

 TERRA DYNAMICS INC

Drawing No.: Figure 4-1.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: TDM
Designed By: DERS 1988
Checked By: DERS 1988



Source: Dodge & Posey, 1981

Drawing No.: Figure 4-2.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Dodge & Posey
Designed By: DERS 1988
Checked By: DERS 1988

FIGURE 4-2

MAJOR STRUCTURAL FEATURES OF THE TEXAS GULF COAST

PREPARED FOR

EXXON MOBIL COPORATION
PASADENA, TEXAS

TERRA DYNAMICS INC

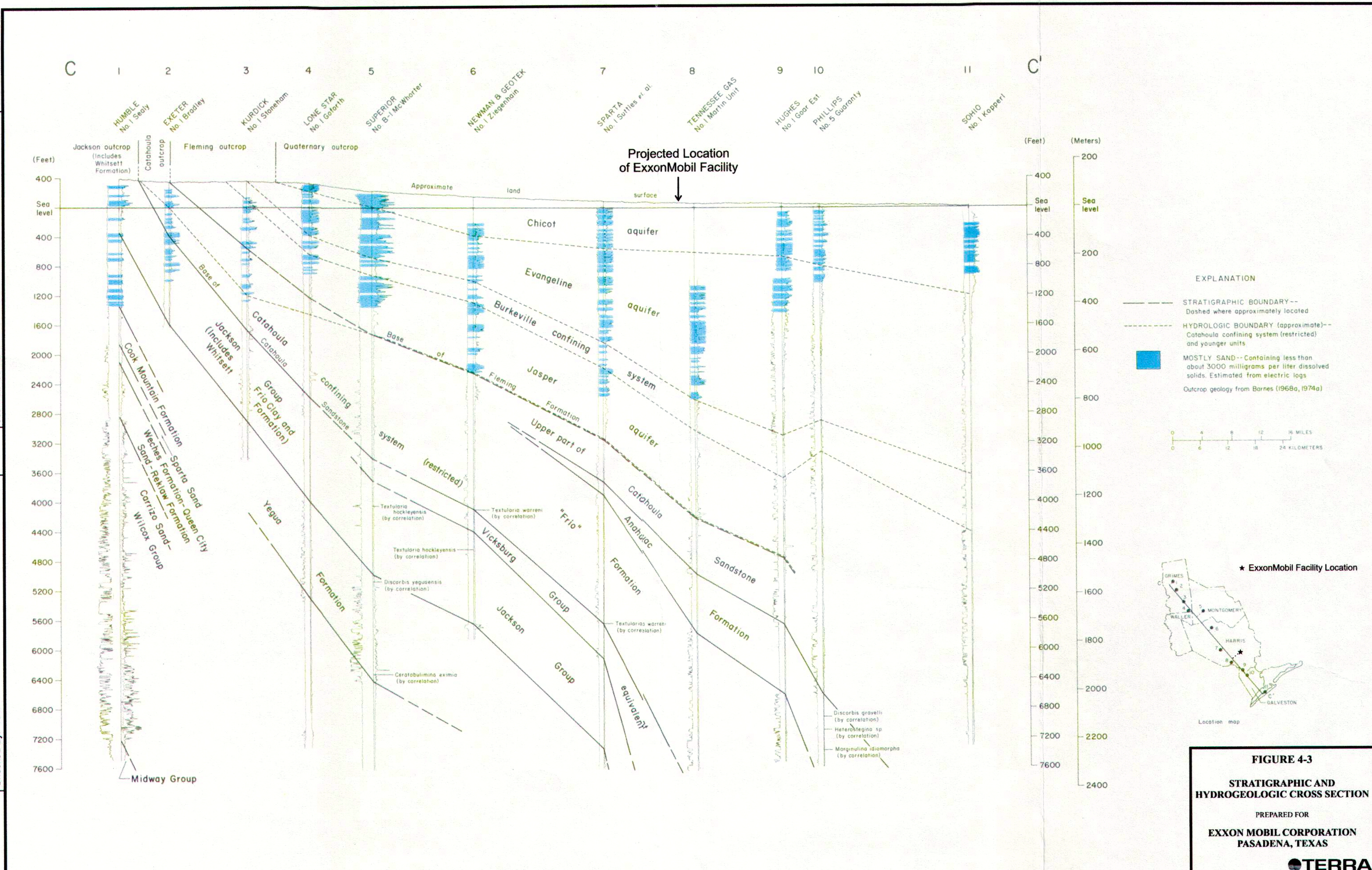


FIGURE 4-3

STRATIGRAPHIC AND HYDROGEOLOGIC CROSS SECTION

PREPARED FOR

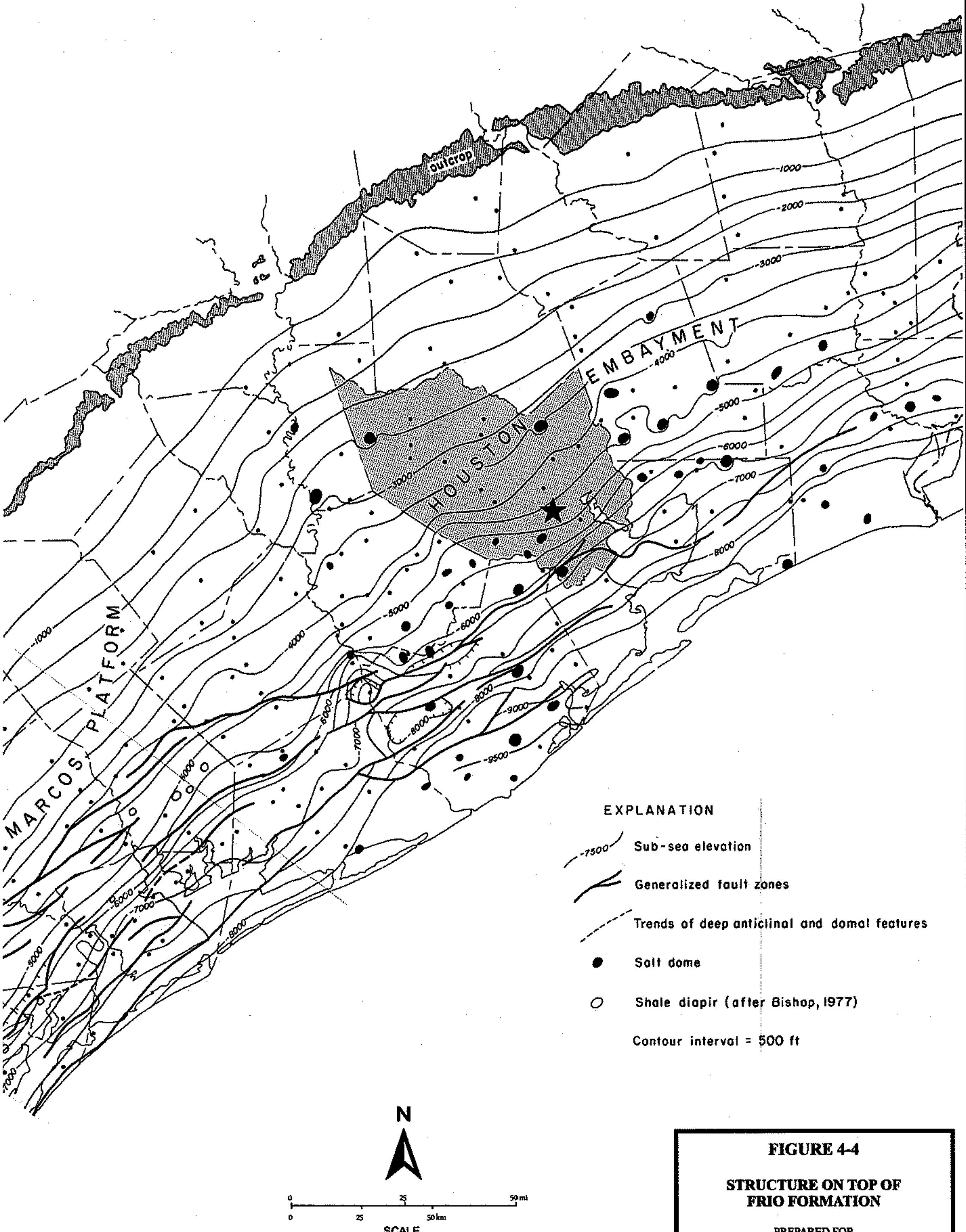
EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC

Source: Baker, 1979

Drawing No.: Figure 4-3.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Baker
Designed By: TDM
Checked By: TDM



★ ExxonMobil Facility Location

Source: Galloway and others, 1982

FIGURE 4-4

STRUCTURE ON TOP OF FRIO FORMATION

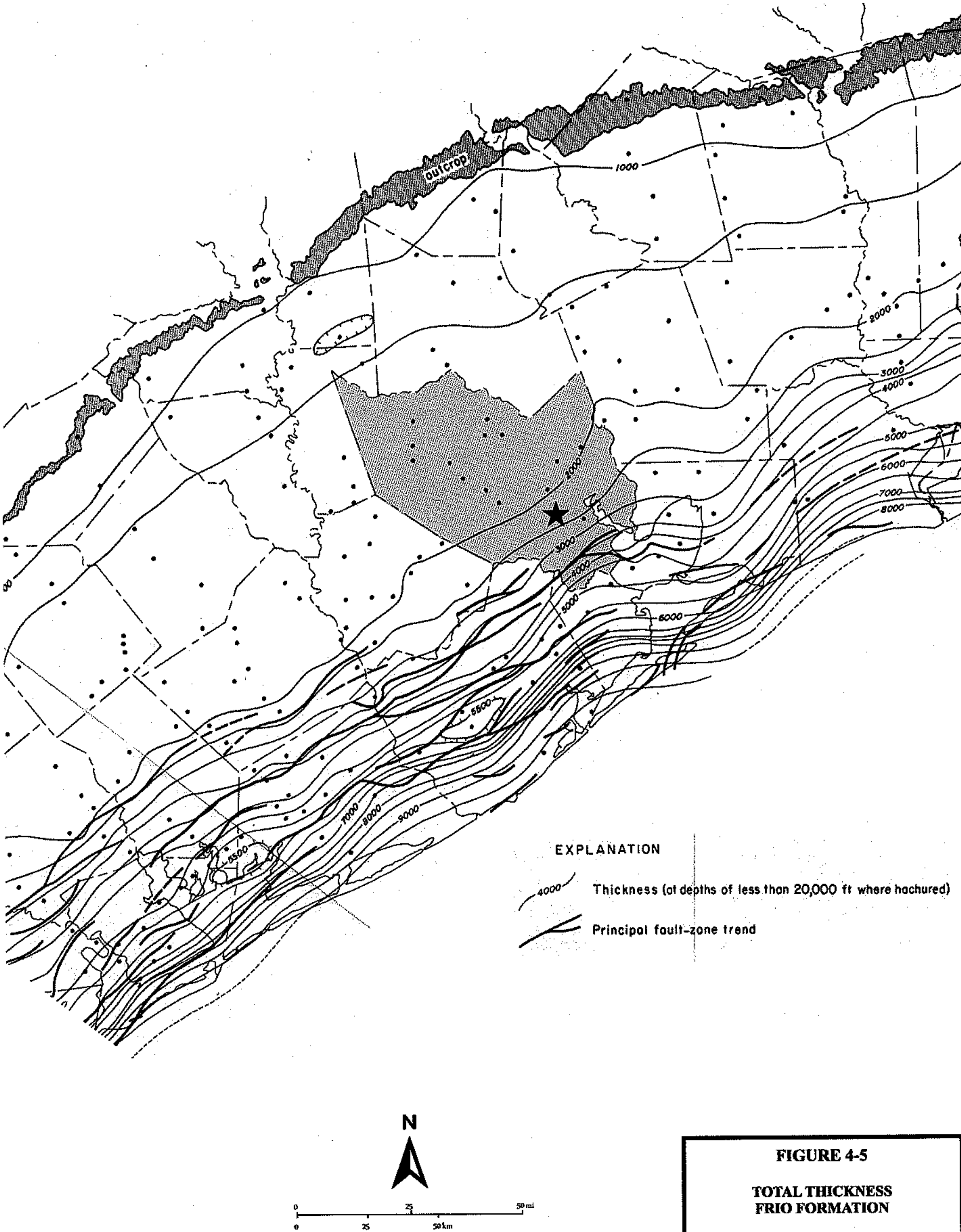
PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

TERRA DYNAMICS INC

Drawing No.: Figure 4-4.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Galloway and others
Designed By: same
Checked By: tdm



★ ExxonMobil Facility Location

Source: Galloway and others, 1982

FIGURE 4-5

TOTAL THICKNESS FRIO FORMATION

PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC

Drawing No.: Figure 4-5.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Galloway and others
Designed By: same
Checked By: TDM

Drawing No.: Figure 4-6.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Dodge and others
Designed By: TDM
Checked By: TDM

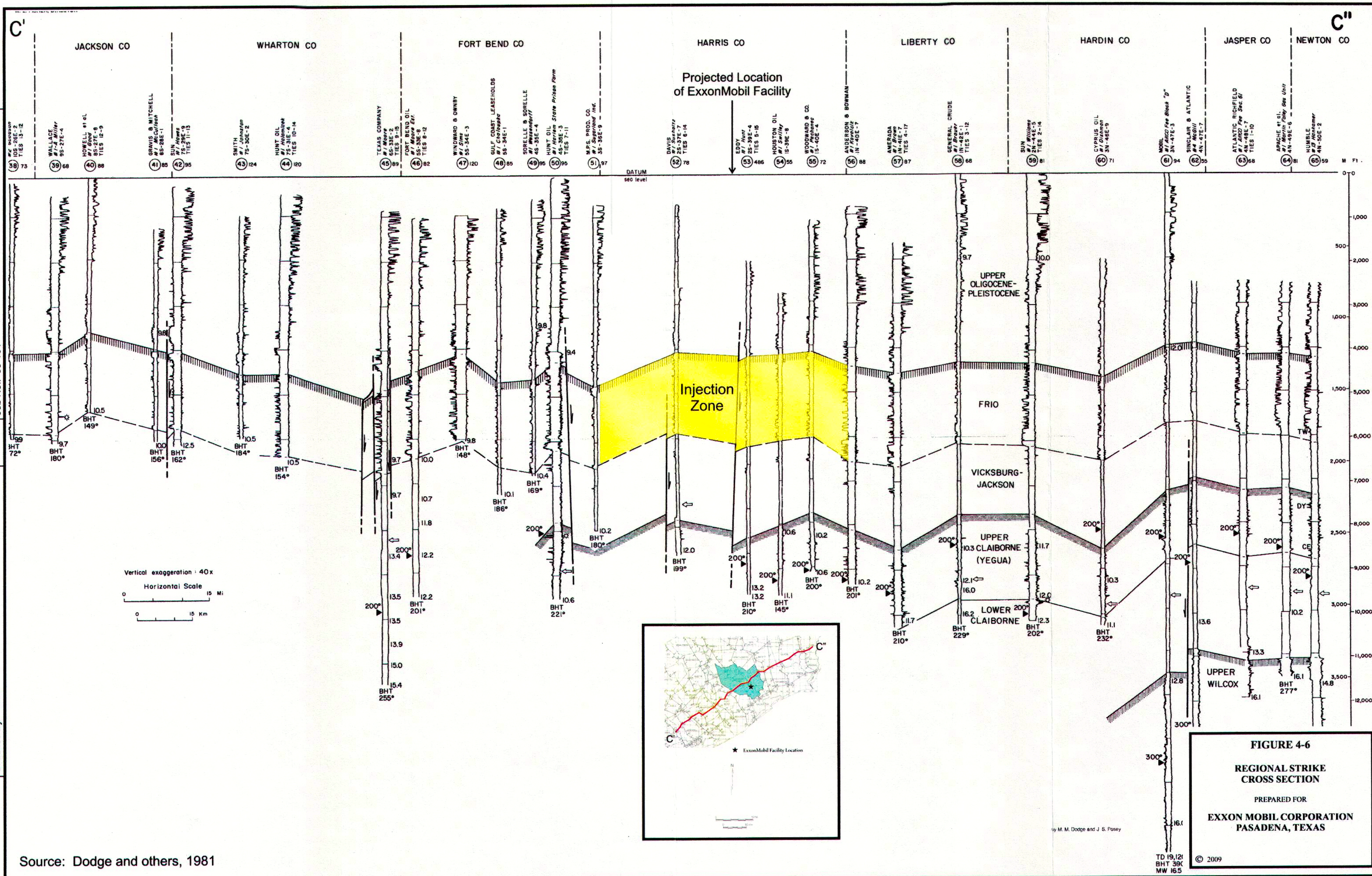


FIGURE 4-6

REGIONAL STRIKE CROSS SECTION

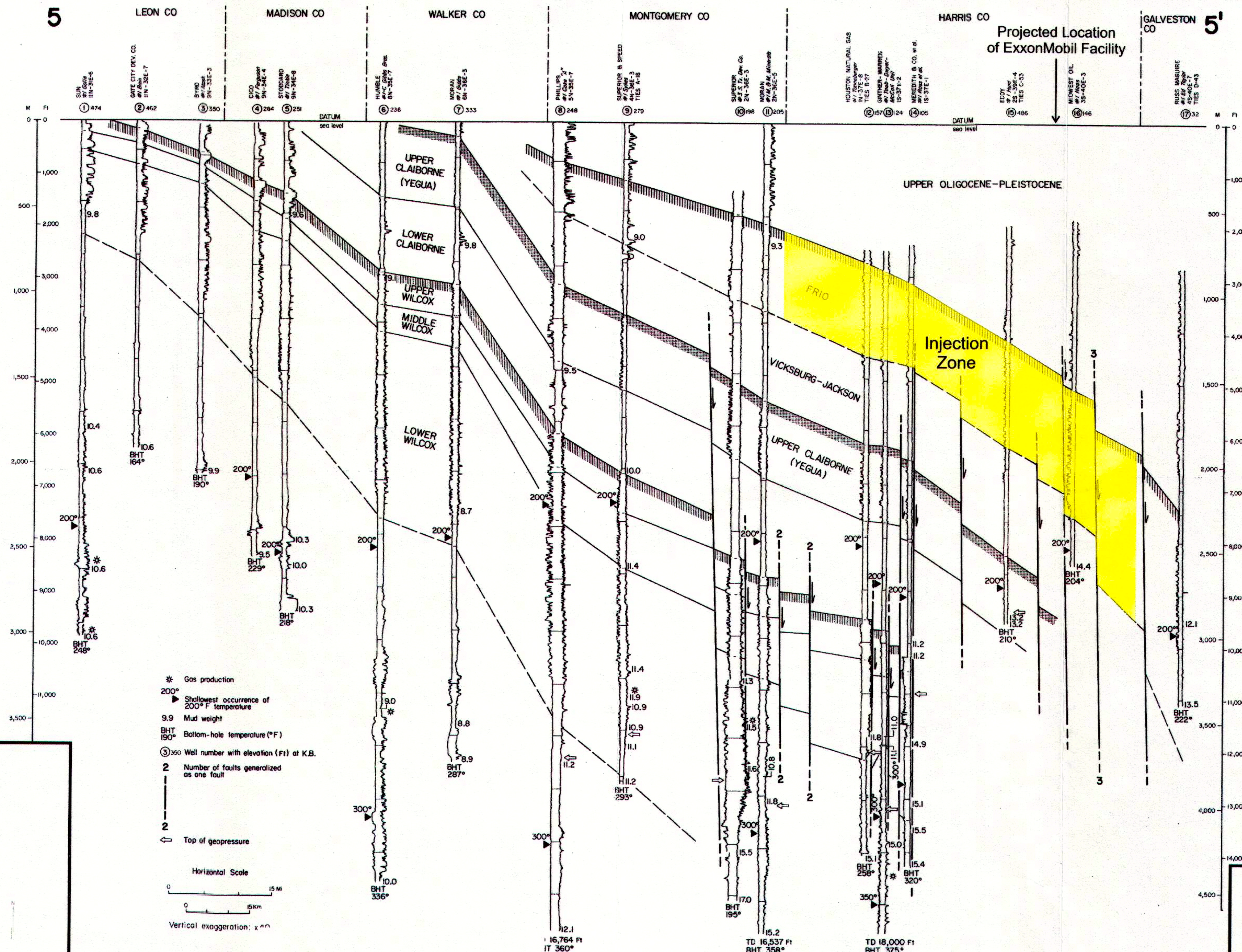
PREPARED FOR

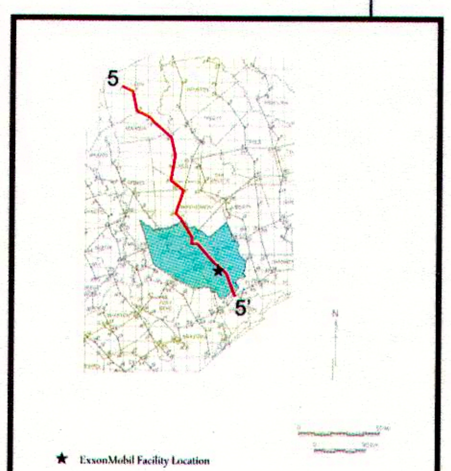
EXXON MOBIL CORPORATION PASADENA, TEXAS

Source: Dodge and others, 1981

Drawing No.: Figure 4-7.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Dodge and others
Designed By: TDM
Checked By: TDM





Source: Dodge and others, 1981

FIGURE 4-7

REGIONAL DIP CROSS SECTION

PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC

Drawn By: Algermissen	Drawing No.: Figure 4-8.cdr
Designed By: Algermissen	Date: 03-11-09
Checked By: TDM	Job No.: 09-104

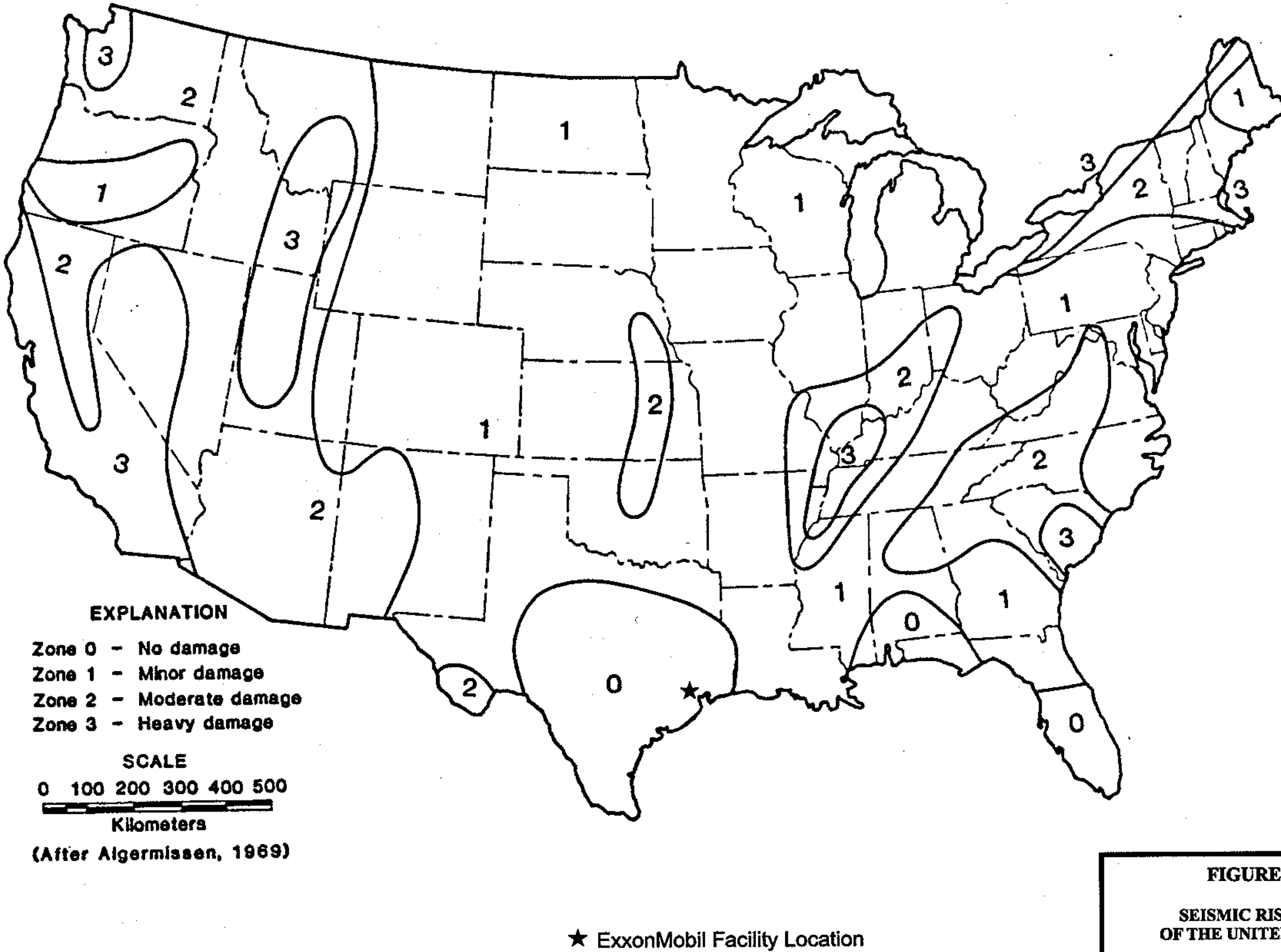


FIGURE 4-8

SEISMIC RISK MAP OF THE UNITED STATES

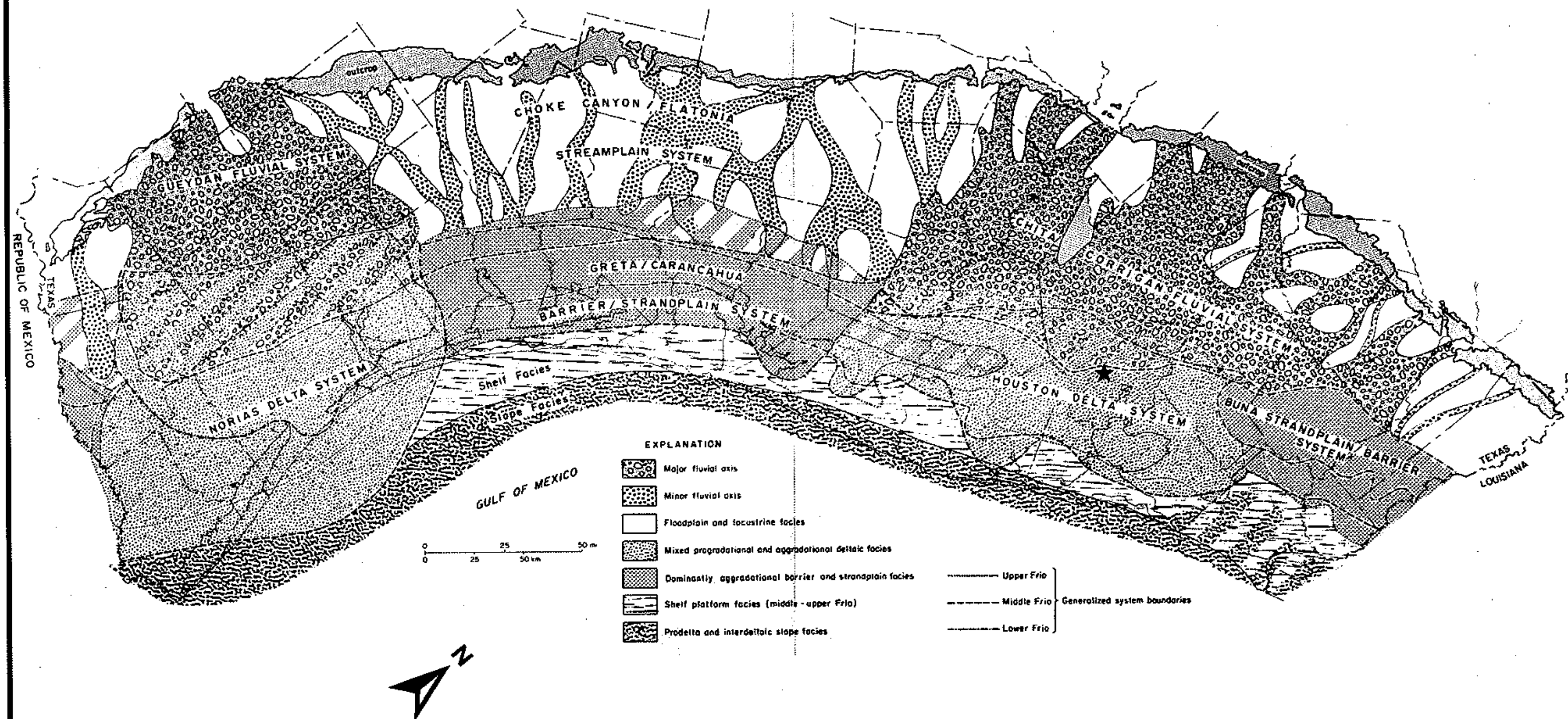
PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC

Drawn By: Galloway and others
Designed By: same
Checked By: TDM

Drawing No.: Figure 4-9.cdr
Date: 03-11-09
Job No.: 09-104



★ ExxonMobil Facility Location

Source: Galloway and others, 1982

FIGURE 4-9

FRIO DEPOSITIONAL SYSTEMS

PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

TERRA DYNAMICS INC

Drawn By: Galloway and others 1986	Drawing No.: Figure 4-10.cdr
Designed By: same	Date: 03-11-09
Checked By: TDM	Job No.: 09-104

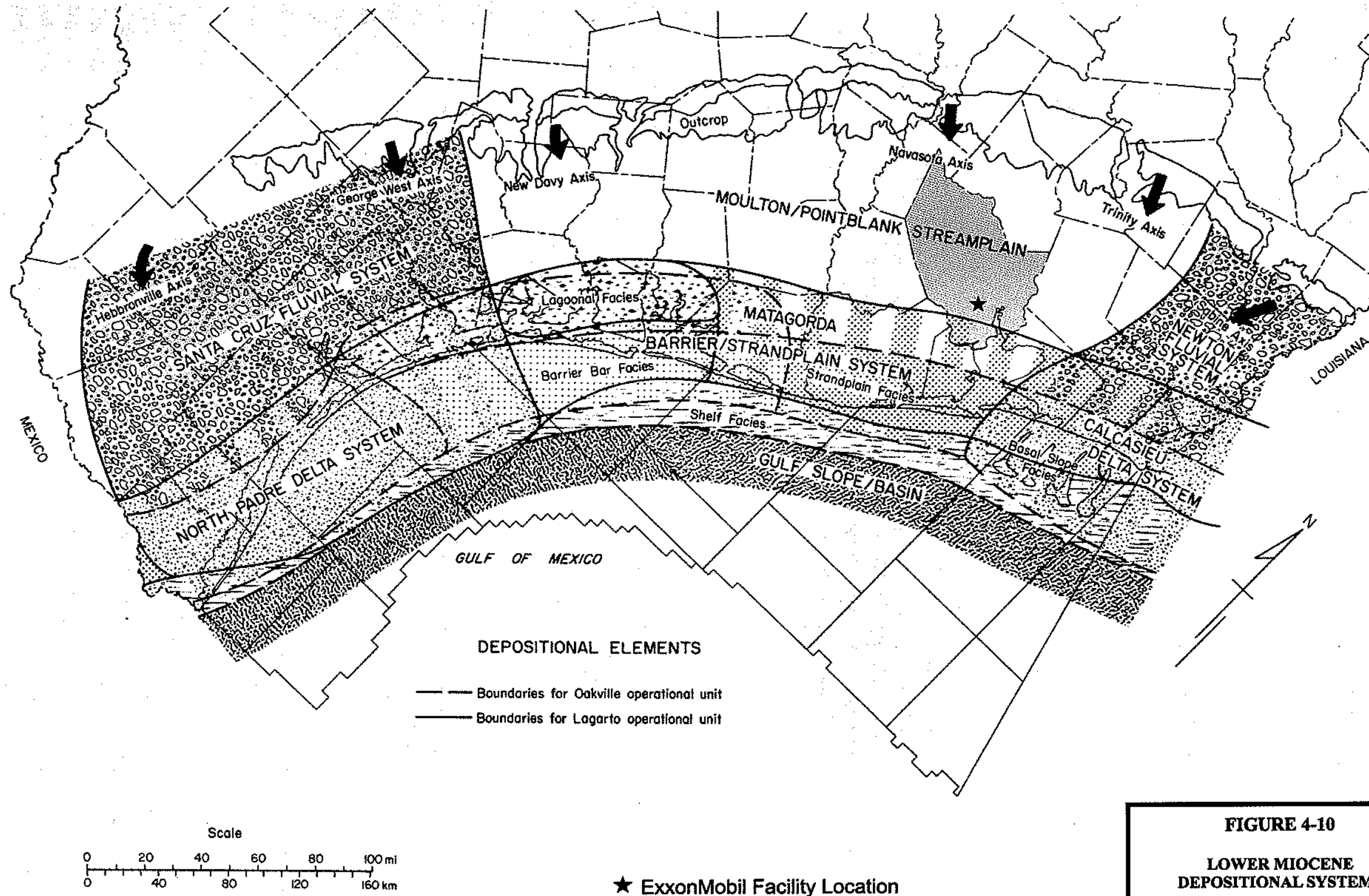


FIGURE 4-10

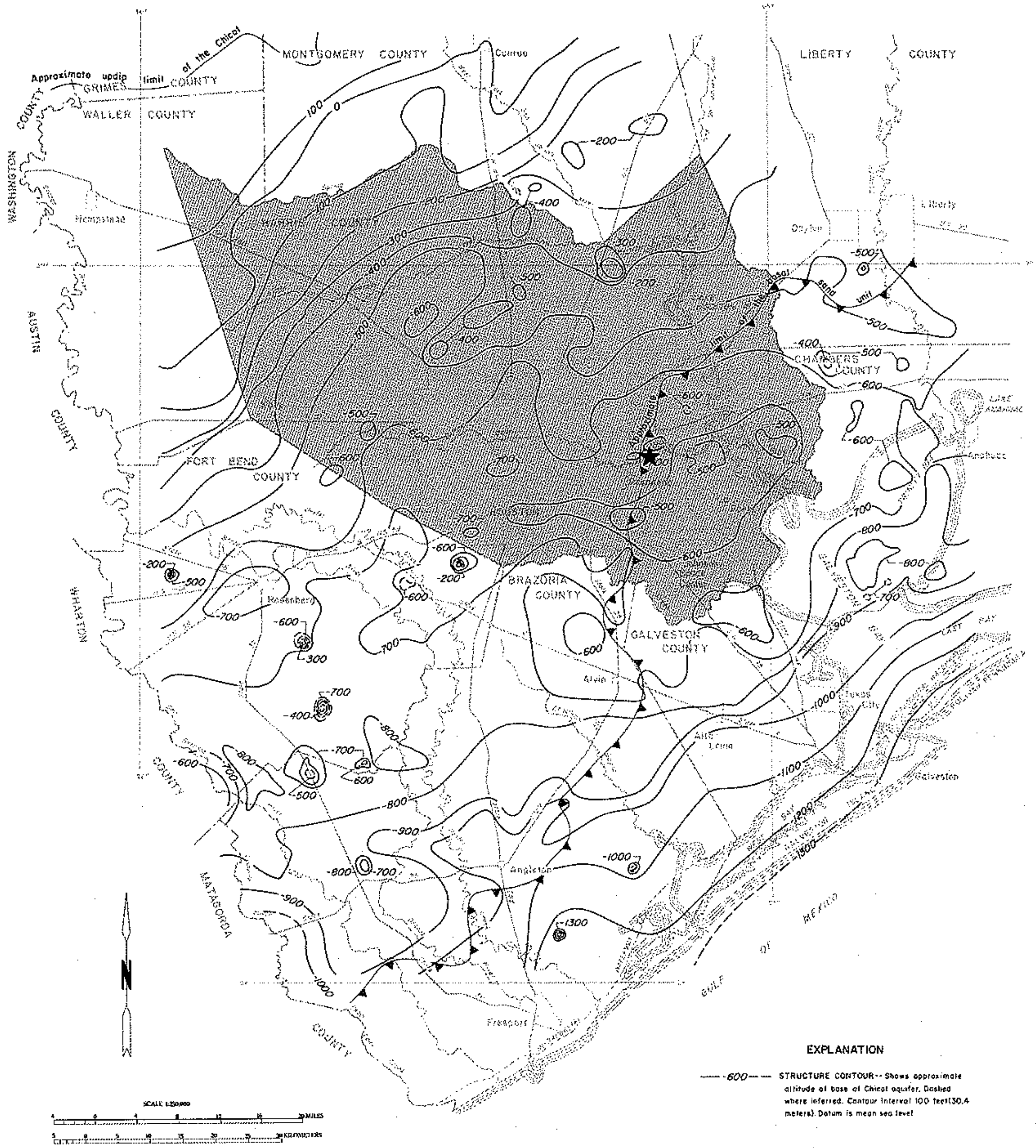
LOWER MIOCENE DEPOSITIONAL SYSTEMS

PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC

Source: Galloway and others, 1982



★ ExxonMobil Facility Location

Source: Gabrysch, 1980

Drawing No.: Figure 4-11.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Gabrysch
Designed By: TDM
Checked By: SKR

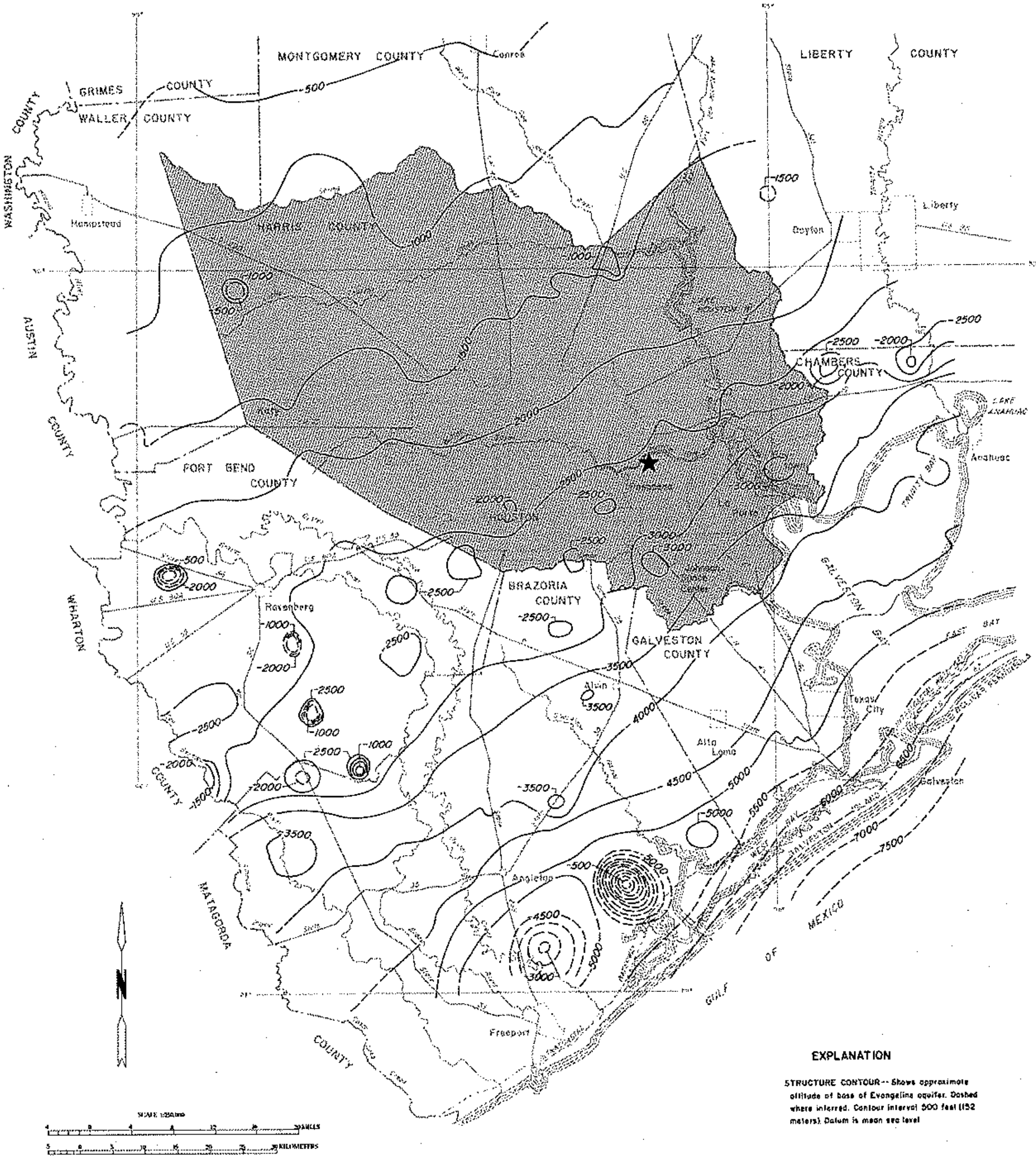
FIGURE 4-11

STRUCTURE CONTOUR MAP ON BASE OF CHICOT AQUIFER

PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

TERRA DYNAMICS INC



★ ExxonMobil Facility Location

FIGURE 4-12

STRUCTURE CONTOUR MAP ON BASE OF EVANGELINE AQUIFER

PREPARED FOR

EXXON MOBIL CORPORATION PASADENA, TEXAS

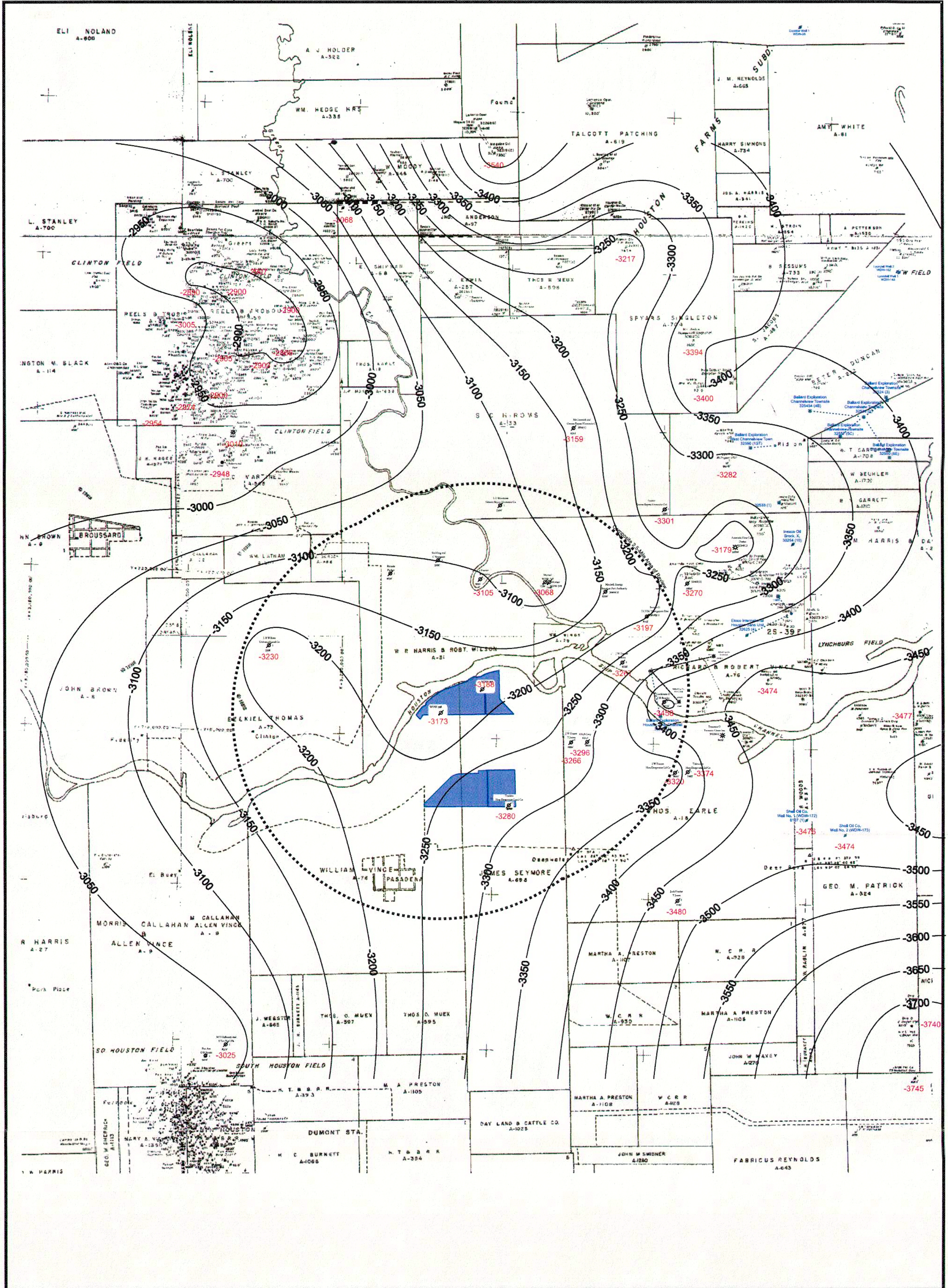
TERRA DYNAMICS INC

Drawing No.: Figure 4-12.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Gabrysch
Designed By: TDM
Checked By: SKR

Source: Gabrysch, 1980

Drawn By: TDM	Drawing No.: Figure 4-13.cdr
Designed By: TDM	Date: Revised: 07-26-10
Checked By: TDM	Job No.: 09-104



LEGEND

- Location
- Location Abandoned
- Rig Up
- Drilling
- Dry & Abandoned
- Oil Well
- Oil Well Abandoned
- Gas Well
- Gas Well Abandoned
- Well Abandoned-Show of Oil & Gas
- Well Abandoned-Show of Oil
- Well Abandoned in Salt
- Well Abandoned in Cap Rock
- Core Test Well
- Wet Gas Or Condensate Well
- Wet Gas or Condensate Well Abnd
- Producing Oil & Gas
- Injection Well

Agrifos Fertilizer and Gyp-Stack Locations

-3150 Line of Equal Elevation in Feet (relative to mean sea level)

-3065 Elevation Base of USDW

Contour Interval = 50 feet

N

SCALE 1 inch = 6,000 feet

3,000 0 3,000 6,000 FEET

Grant Or Section Line
County Line
State Line
Line Visible On Aerial Photo

Base Map Source: Tobin Research, 2002

FIGURE 4-13

STRUCTURE MAP
BASE OF USDW
(Underground Source of Drinking Water)

PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

TERRA DYNAMICS INC

Project Location and Approximate Composite 2.0-Mile Radius

Pit or quarry, commonly in fluvial deposits

Sludge pit or miscellaneous waste disposal site, may be abandoned

Sewage disposal site, liquid effluent, normally treated

Solid waste disposal site, sanitary landfills, and open dumps

Salt dome, shallow piercement, projected outline (approximate) of dome, normally surface expression

Active or potentially active fault, based on lineament or grain displayed on aerial photographs, some faults near Houston from published sources

Source: Fisher and others, 1972

FIGURE 4-14

SURFACE LINEAMENT MAP

PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

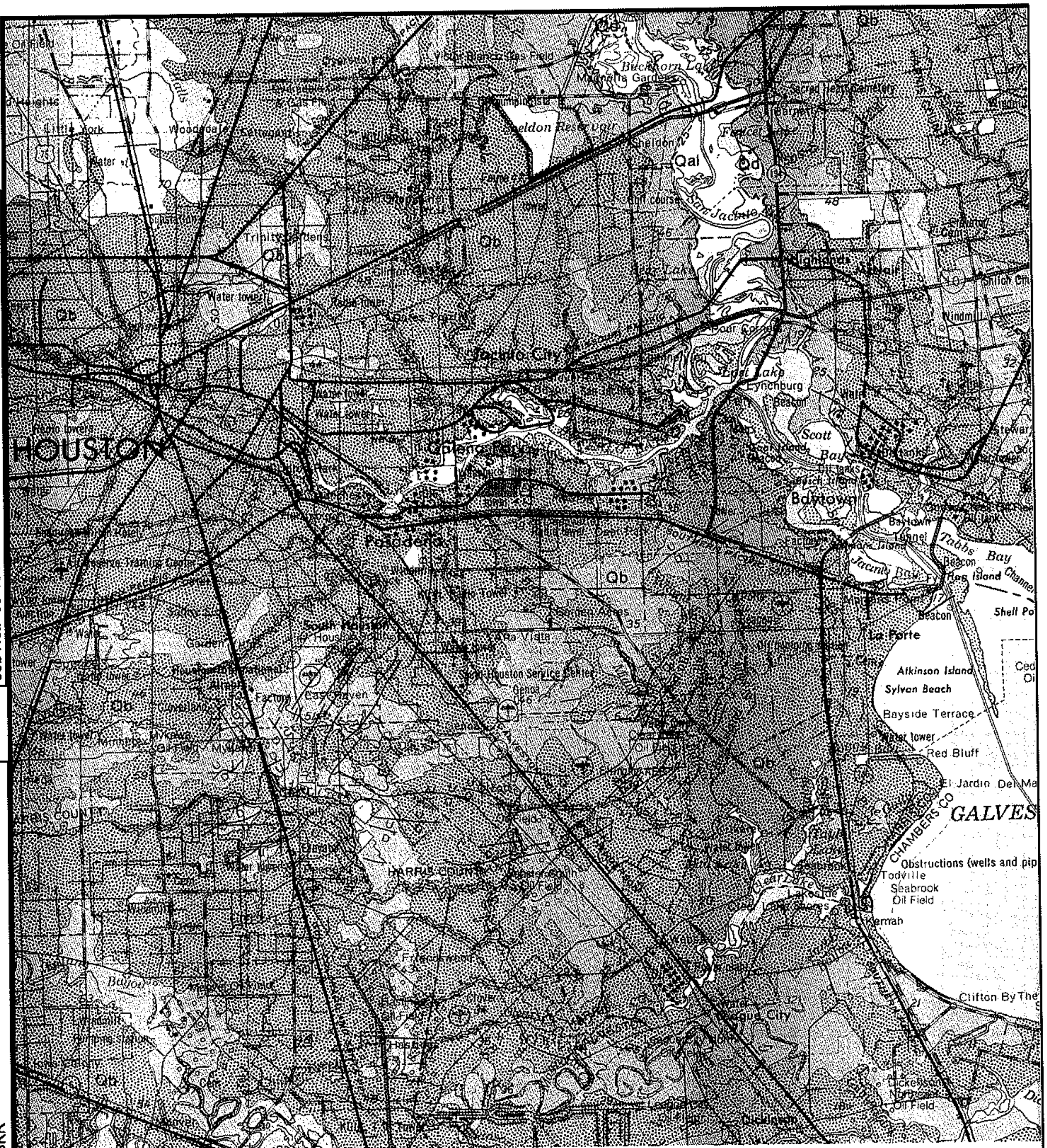
TERRA DYNAMICS INC

Drawing No.: Figure 4-14.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Fisher and others
Designed By: TDM
Checked By: SKR

Drawing No.: Figure 4-15.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: Fisher
Designed By: TDM
Checked By: SKR



EXPLANATION

FS Fill and spoil

Qal Alluvium

Qd Qd' Deweyville Formation

Qb Qb Qb' Beaumont Formation

Ql Lissie Formation

Project Location and
Approximate Composite 2.0-Mile Radius

N

Source: Fisher, 1982

FIGURE 4-15

GEOLOGIC ATLAS OF PROJECT LOCATION

PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

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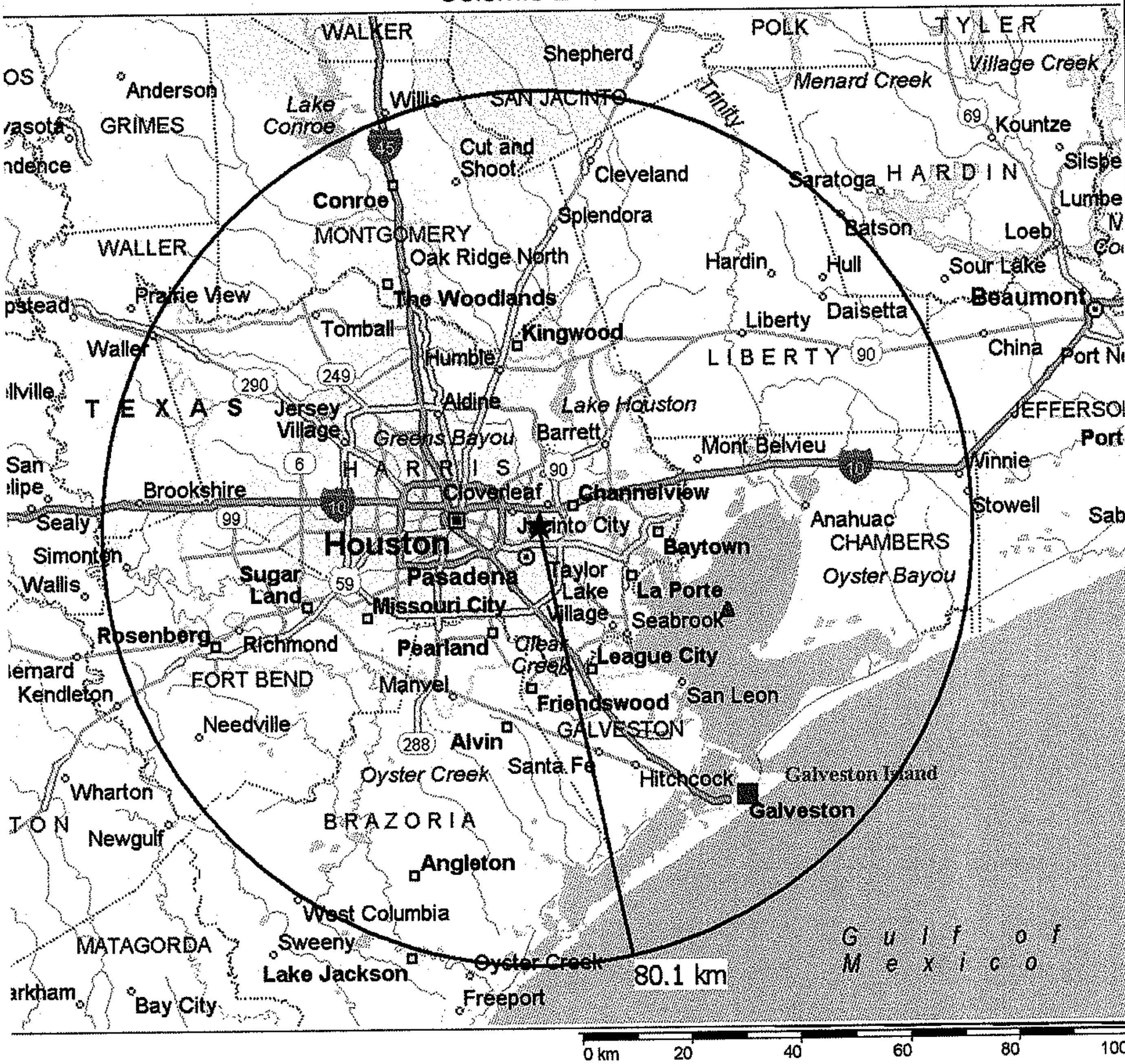
Seismic Events



■ 1956 Event (Magnitude of 3.8)

▲ 1925 Event (No reported magnitude or intensity)

N

★ ExxonMobil Facility Location

Source: United States Geological Survey, 03/11/2009

FIGURE 4-16

SEISMICITY WITHIN 80 KM OF EXXONMOBIL FACILITY

PREPARED FOR

EXXON MOBIL CORPORATION
PASADENA, TEXAS

TERRA DYNAMICS INC

Drawing No.: Figure 4-16.cdr
Date: 03-11-09
Job No.: 09-104

Drawn By: TDM
Designed By: same
Checked By: TDM